AD NUMBER

ADB130217

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to DoD only; Premature Dissemination, Sep 87. Other requests shall be referred to Army Missile Command, ATTN: AMSMI-RD-SE, Redstone Arsenal, AL 35898-5270.

AUTHORITY

DFOISR/WHS/DOD ltr, 30 Nov 2001

95/ 224

DTIC FILE COPY

(2)

AD-B130 217

TECHNICAL REPORT RD-SE-88-1

PRODUCIBILITY ANALYSIS OF THE ALTERNATIVE ANTITANK AIRFRAME CONFIGURATION (AATAC) FLEX-WING

Sam B. Wood
Richard W. Amos
Barbara J. Robertson
Harold R. Brewer
Susan D. Bowles
System Engineering and Production Directorate
Research, Development, and Engineering Center

JUNE 1988

U.S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama 35898-5000

Distribution ~~limited~~ units to DOD only; Premature Dissemination, September 1987. Other requests must be referred to this Command, ATTN: AMSMI-RD-SE.

89

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188
Exp Date Jun 30, 1986

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Distribution E - See Page ii
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) RD-SE-88-1	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION System Engineering and Production, Directorate, Res. Dev. and Engr Center 6b. OFFICE SYMBOL (If applicable) AMSMI-RD-SE	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Commander U.S. Army Missile Command ATTN: AMSMI-RD-SE Redstone Arsenal, AL 35898-5270	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO

11. TITLE (Include Security Classification)
Producibility Analysis of the Alternative Antitank Airframe Configuration (AATAC) Flex-Wing

12. PERSONAL AUTHOR(S)
Sam B. Wood, Richard W. Amos

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM May 86 TO Sep 87	June 1988	112

16. SUPPLEMENTARY NOTATION

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
AATAC Flex-Wing
Producibility Cost Analysis
Material Impact Assessment

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This report documents the results and findings of a two-year producibility analysis performed on the AATAC Flex-Wing. The first year's report analyzed material selection, manufacturing processes, and cost analysis for the wing design, wing clip, center fuselage, and the wing base of the AATAC Flex-Wing. The second year's report isolated its efforts on the wing design only. Material impact, cost analysis, drawing tolerance review, and manufacturing process changes were assessed. Summaries and conclusions are provided.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL Sam B. Wood	22b TELEPHONE (Include Area Code) (205) 895-4239 22c. OFFICE SYMBOL AMSMI-RD-SE-PE

Continued from page i:

Block 3 - DISTRIBUTION E - Distribution limited to DOD only; Premature Dissemination, September 1987. Other requests must be referred to this Command, ATTN: AMSMI-RD-SE.

CONTENTS

CONTENTS (Continued)

CONTENTS (Continued)

LIST OF ILLUSTRATIONS

LIST OF TABLES

PREFACE

This report presents the results and findings of a two-year producibility analysis of the Alternative Antitank Airframe Configuration AATAC Flex-Wing. Part One contains the FY 86 Report and the FY 87 Report is presented in Part Two.

FY 86 Report. The first year producibility analysis was not limited to the wing design only, but included consideration of various production processes of the wing base, center fuselage, and clip. The report included a study of process repeatability, weldability of 17-7 PH stainless steel, and comparison of pertinent characteristics of potential material candidates.

Stress corrosion cracking was investigated; it was concluded that a metal with at least 45 percent to 50 percent Nickel would be free from stress corrosion cracking (SCC). Hence, MP35N would be relatively SCC resistant, but was considerably more costly than other alternative materials. Other materials, 14-8MO and 15-7MO, in addition to the 17-7 PH (currently used for the wind), were also investigated. No major design changes were recommended. No major problems were foreseen in transitioning of TOW 2 to the proposed AATAC design. There will be no need for additional facilities. There will be some additional cost, approximately $80 per missile, due to the different wing fabrication involved.

FY 87 Report. The current fabrication processes for the AATAC Flex-Wing were identified and a brief description of each step was given. The current manufacturing method was used to perform a production cost estimate. Results yielded a production cost of $20 per wing. Alternate manufacturing methods were considered and blanking, trimming, wing half shaping and spot welding were identified as cost drivers. The introduction of high rate automation and process changes to key cost drivers could lower costs by 75 percent, or down to $5 per wing. Drawings were analyzed and reviewed by Production Engineering Division (PED) and tolerances appeared to be adequate. PED suggested a design change to aid the wing tab folding process. PED's concerns about material transformation in the wing halves spot welding process were presented, and copper beryllium was presented as a candidate material to replace stainless steel 17-7 PH.

PART ONE

FY 86 - FIRST YEAR REPORT

I. INTRODUCTION

The Alternative Antitank Airframe Configuration (AATAC) program is designed to develop an alternate wing configuration for the TOW 2 missile in order to utilize space occupied by the existing wing placement for other purposes. The program is designed to demonstrate technical feasibility of the new airframe configuration and evaluate alternative utilization plans for the vacated space in the TOW 2 (see Figure 1). As a part of the AATAC program, the Production Engineering Division (PED) was tasked by the Structures Directorate to assist in the evaluation of the production feasibility of the AATAC wing configuration. This effort was initiated in order to provide consideration of production issues early in the design phase in an attempt to help reduce and control ATAC life cycles costs.

A. Problem Statement

The specific tasks identified by the Structures Directorate included the following:

1. Become familiar with the AATAC prototype production efforts ongoing at the Jet Propulsion Laboratories (JPL) and the Prototype Engineering Division of System Engineering and Production Directorate (SEPD). Monitor the production progress of each group, and document and evaluate the manufacturing procedures used by each group in the fabrication of AATAC hardware.

2. Perform the analyses necessary to evaluate candidate processes for the manufacture of AATAC hardware. Recommend the most economical manufacturing processes for high rate AATAC production.

3. Develop engineering cost estimates for the production of AATAC wings and associated mounting hardware.

4. Identify the potential impact of AATAC wing configuration phase-in on TOW 2 production operations.

B. Methodology

The evaluation of the AATAC wing design producibility was conducted in-house by PED. The production process recommendations were developed using techniques developed specifically for use on the Research, Development, and Engineering (RD&E) Center programs. The cost evaluation was conducted using various costing algorithms developed by PED. The information regarding current TOW 2 production status was compiled by members of PED's Land Combat Systems Group in conjunction with SEPD field office representatives in the Hughes Aircraft Company (HAC), Tuscon, AZ, manufacturing facility. Actual TOW production cost data was utilized for comparison purposes wherever possible. The production rate chosen as a baseline for cost analysis purposes was 2500 units per month. This rate was chosen through comparison of current and projected TOW 2 production rates in order to provide an accurate representation of the AATAC production environment.

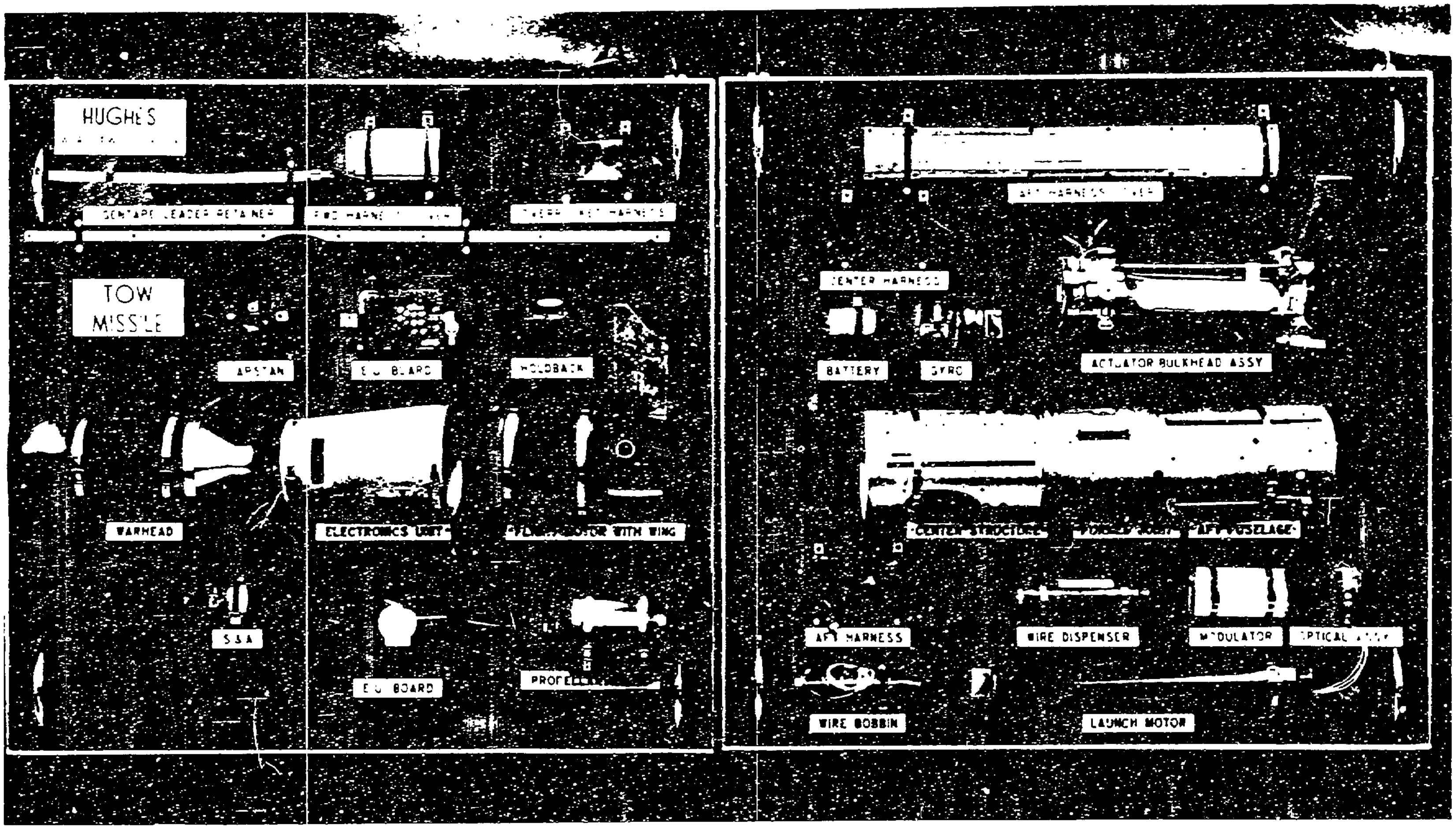


Figure 1. TOW 2 missile.

C. Design Baseline

The producibility analysis was performed using AATAC design concepts and drawings prepared by MICOM (Sperry) and JPL personnel. The parts analyzed and discussed in this report include:

PARTS LISTING

Part	Designer	Origin	Drawing Number
A-3 Wing	Lou	JPL	N/A
A-3 Clip	Bamford	JPL	N/A
Center Fuselage	Gibson	MICOM	RD-ST-WF-307
Base Plate	Gibson	MICOM	RD-ST-WF-304

Part sketches developed by JPL and used in this analysis are included in Appendix A.

II. PRODUCTION/PRODUCIBILITY CONSIDERATIONS

In general, the parts associated with the AATAC design concept can be produced with fairly conventional manufacturing operations. The wing and clip production require a fairly high operator skill level and could produce some problems in a high rate production environment. In the course of early discussions with manufacturing personnel at JPL and SEPD's prototype shop, several concern areas were identified. Upon completion of the initial producibility analysis, the remaining production considerations can be grouped into the catagories of (1) High Rate Manufacturing Issues; and (2) Wing Material Selection.

A. High Rate Manufacturing Issues

1. Process Repeatability

In order to realize economical production conditions in any high rate manufacturing environment, a high degree of production process repeatability must be attained and maintained. The AATAC case is no different. The production of the Center Structure and Base Plate can be accomplished using a combination of precision casting amd machining operations. The design requirements (surface finishes, tolerances, wall thicknesses, etc.) are, in general, within the range commonly considered to be "economically producibile" and should present few manufacturing related problems. The wings and clips are of a higher degree of manufacturing difficulty, and as such, will warrant additional consideration. During the performance of this producibility analysis, special attention was given to those production processes which would be expected to provide a high degree of process repeatability at the projected production rates.

2. Weldability of 17-7 PH Stainless Steel

The economical manufacture of the flex-wing assembly will require a joining process which will produce a strong, clean, homogeneous joint and which does not require post weld machining, straightening, cleaning or heat treating. A process particularly suited to joining thin sheets of precipitation hardenable stainless steels is Resistance Spot Welding (RSW). RSW is a process in which contacting surfaces are metallurgically joined in spots by the heat generated from the resistance to the flow of electrical current through workpieces held together under force by electrodes. RSW manufacturing advantages include ease of operation and adaptability to automation. Limitations of RSW are the equipment expense and power requirements. Nonrecurring equipment costs for RSW includes a power supply, control equipment and fixtures. Recurring manufacturing costs are primarily direct labor and electrode costs. Electrode life is a critical factor in the RSW process. During the welding operation, the electrodes are subject to great compressive stresses at elevated temperature and must be frequently dressed and periodically replaced.

Semiaustenitic precipitation hardened stainless steels are readily RSW in the hardened condition. A narrow heat affected zone transforms and remains austenitic after cooling. Cracking in the heat affected zone should not present a problem. As previously stated RSW is a high speed production process, suitable for automation. Most of the process time involves alignment of weldment and removal from fixtures, actual welding times are only a fraction of a second. RSW operations are commonly included in high production assembly lines with other fabrication operations. Automatic control of process variables, such as current, dwell timing, and electrode force allow operation at low unit labor costs by semiskilled operators.

A possible alternative method of joining the flex-wing assembly would be Electron Beam Welding (EBW). EBW would produce a weld with a very narrow heat affected zone. However, very high production quantities are needed to amortize the extremely high capital equipment costs. Hence, the greatest gain in producibility of the AATAC wing can be obtained by assuring proper alignment and fixturing of the part using RSW.

B. Wing Material Selection

Discussions with designers at the JPL revealed JPL's concern about the selection of 17-7 PH steel as the wing material. The AISI 631 stainless steel alloy, ARMCO trade designation 17-7 PH, used to fabricate the flex-wing is a semiaustenitic precipitation hardenable stainless steel. This family of alloys is produced in most all forms and is readily available in strip and sheet products. Typical costs for the alloy in thin sheet sections range from $10 to $12 per pound. Concern has been expressed by the JPL over the susceptibility of 17-7 PH stainless steel to exhibit stress corrosion cracking (SCC), induced by bending of the flex-wing during long periods of storage. PED engineers discussed the problem at length with JPL personnel and have researched the problem. Several factors are involved in the wing material selection decision process.

1. Shelf Life/SCC

The mechanism of accelerated corrosion by static stress is generally agreed to be caused by energy stored in the distorted metal which makes it less noble, or caused by a variance in electrical potential of the metal. Investigations have shown that increasing the nickel content above 8 percent is beneficial, but complete immunity to this type of cracking is not reached until the nickel is higher than 45 to 50 percent. However, such alloys are expensive and not commercially available.

2. Comparison of Candidate Alloys

The scientists at JPL have suggested AMAX Speciality Metals Corporation's MP35N alloy as an alternative to the use of 17-7 PH steel in wing fabrication. This is a high nickel content alloy which would eliminate any possibility of SCC which might exist. However, the alloy is quite specialized, and as such, is quite expensive. In addition, the alloy contains elements which are considered "critical" by the U.S. Army, and whose use should be avoided if possible. JPL also suggested the use of 14-8 Moly steel in wing fabrication. PED's investigation of this alloy revealed that the product is not currently being produced in the United States. Several sources are capable of producing it, but the startup costs could be very high. Another alternative is to use 15-7 Moly steel. This alloy should provide slightly better SCC resistance at a price which is comparable to the 17-7 PH.

The following table gives a comparison of the alloys, their chemical composition, purchase price, and material cost to produce one wing:

TABLE 1. Comparison of Candidate Alloys.

Material	Chemistry	Price (1 lb)	Material Cost/Wing	Notes
17-7 PH	17% Cr, 7% Ni	\$ 9-12	\$ 1.62	Current Material
MP35N	35% Ni, 35% Co 20% Cr, 10% Mo	\$ 90	\$14.90	Sole Source, Critical Material, Alt. Heat Treat Req.
14-8 Mo	14% Cr, 8% Ni, 2% Mo	\$15-20	\$ 3.00	Not Being Produced
15-7 Mo	15% Cr, 7% Ni, 2% Mo	\$9-12	\$ 1.62	Similar Processes as 17-7 PH

3. Recommended Material

The results of the review of the manufacturing and producibility related considerations of alternative materials indicate that the current material, 17-7 PH steel, is the best alternative for flex-wing fabrication. Therefore, it is suggested that further research be conducted to determine the true potential of SCC before a commitment is made to change wing material.

III. PRODUCTION PROCESS SELECTION

One of the key results of any producibility analysis is the identification of the most economical production process for each part. The following sections describe PED's methodology for determining the most economical manufacturing method, and detail the results of the producibility analysis for the AATAC wing configuration.

A. Process Capability Analysis

The Production Planning and Control Group of the PED has developed an evaluation and rating method for recommending and selecting a manufacturing process capable of producing a particular part of a system. The rating system is called a Process Capability Analysis and is divided into three major catagories: (1) design characteristics, (2) total cost, and (3) second order variables. Design characteristics consist of all physical allowances and limitations specified in the drawing package. These include minimum hole diameter, tolerances, surface finish, and minimum wall thickness. The total cost is used in order to provide the client with the most efficient method of producing the part for the given quantity. Included in the analysis is a study of raw material costs, production costs, and tooling costs. The cost analysis is based on the assumption that at least 10,000 parts will be produced. The second order variables consist of all factors that influence the manufacturing environment, yet do not directly effect the production costs or design requirements. These variables include lead-time, applicable materials, and mechanical properties.

The rating system used in this analysis is a comparative, or tradeoff comparison, system. Each catagory is chosen and a comparison is made between several manufacturing techniques. The techniques considered most often were machining, forging, extrusion, powder metallurgy, permanent mold casting, die casting, investment casting, and plastics molding. The comparison is made using relational numeric values. Design characteristics for each production alternative are given a rating depending on how they compare to the desired design specification. Cost factors are given relational scores based on a comparison with similar attributes for the alternative manufacturing methods. The values for each process are then summed, and the method with the highest score is chosen as the best alternative for manufacture of the part.

B. Production Processes Considered

In performing the AATAC producibility analysis, four mass production metal forming processes received primary consideration. These four processes: permanent mold casting, investment casting, die casting, and powder metallurgy, were chosen due to the suitability for precision, high quality, and high volume production. For each AATAC part, the four processes were compared against the more traditional processes of machining and, if applicable, forging and extrusion. The following sections present a basic overview of the process parameters and their applications.

1. Permanent Mold Casting

The permanent mold casting process employs gravity to introduce the metal to the mold. The molds most commonly are made of fine grain cast iron or steel. Aluminum, magnesium or copper based alloys are the most common casting materials. A rigid mold offers great resistance to shrinkage of the casting. As a result, only relatively simple shapes are cast by the permanent mold process. Because of the nature of the mold, permanent mold castings have very good dimensional accuracy and smooth surface finishes. Solid die tolerances for aluminum and magnesium alloys are ± 0.015 inches up to the first 1.0 inch, and ± 0.002 for each additional inch increment. Copper based alloys have solid die tolerances of ± 0.015 inches up to the first inch, and ± 0.005 inches for each additional inch increment. In general, permanent mold casting provides greater flexibility and less lead-time and cost where medium production quantities are involved.

2. Investment Casting

The investment casting process makes possible the casting of a wide range of shapes and contours in small size parts. Although it is more costly than the other casting processes, the investment process offers low cost solutions to problems where the part is small, the metal is hard to work or machine, and intricate contours and an excellent surface finish is needed. With investment casting there are definite size limitations, expensive patterns and molds, and a high labor cost, but investment casting produces high dimensional accuracy, surface finish and intricacy. Physical properties that can be expected from this process include tolerances that range from ±0.002 to ±0.062, draft allowance of 0 to 0.5 degrees and size allowances from ounces to 100 pounds. Investment casting will accommodate lot sizes in the thousands, but is better suited for small lot sizes. Investment casting is also advantageous when casting very thin pieces, some as thin as 0.015 inches. Although this process is complicated and rather expensive, the surface finish is so smooth that it proves to be a cost efficient manufacturing process due to the small amount of machining necessary to finish the part.

3. Die Casting

Die castings offer the user of high volume, small, nonferrous castings an exceptionally profitable combination of low cost and maximum design flexibility. Advantages of the die casting process include smooth surface finish, dimensional accuracy and intricacy with a rapid production rate. On the other hand, there are size and material limitations and a high tooling cost. Die casting is typically used for casting motors, office equipment, and optical equipment. The most common materials used are zinc, aluminum, brass, tin, and magnesium. The expected dimensional tolerances range from ±0.001 to ±0.005 inch.

4. Powder Metallurgy

Powder metallurgy is a process in which finished parts are produced from metallic and/or nonmetallic powders by compaction. The process includes making powders from the raw materials, blending the powders homogenously (usually adding a lubricant), compacting the powders into shape in a die, sintering by heating below the melting point, but allowing diffussion, and finishing the part by machining, heat treating, etc. The equipment needed includes a compaction press, ancillary equipment/tooling, dies, blenders, a sintering furnace, and an atmospheric gas supply. Powder metallurgy's ease of automation lends the process to mass production through the use of advanced conveyor system, high production rate presses, and large capacity sintering furnaces. The powder costs for this process are usually high, but the economic advantages of the process include low equipment costs, low scrap loss, and a high degree of process flexibility. The mechanical advantages of this process include controlled porosity, the ability to obtain unusual material properties, a high product strength to weight ratio, and the ability to work with materials which cannot be formed using traditional casting processes.

5. Centrifugal Casting

Centrifugal casting is a process by which castings are formed as a result of the centrifugal forces developed by rotating a mold about its axial center line. This process is used to produce products which are symmetrical about their center line. A dry sand or metal mold can be used depending on the required surface finish. Centrifugal casting is commonly used in the mass production of pipe, pressure vessels, and other cylindrical shapes. The equipment costs for smaller parts are relatively inexpensive. Mold costs for this process are relatively high, but the molds have very long life so that the nonrecurring costs, on a per unit basis, will be fairly low as compared to other casting processes. The commercially available surface finishes are in the 20-300 microinch range. Tolerances of .01 inches per inch are readily attainable, and attainable production rates are similar to those for permanent mold casting. Also, scrap losses for this process are lower than those for other casting type processes, and yields of 90 percent are commercially attainable.

C. Recommended Production Processes

A Process Capability Analysis (as described in Section III.A) was performed on each of the parts in the design baseline. The results of the analyses and a discussion of each part are presented in the following sections. Process Capability Analysis worksheets for each part are presented in Appendix B.

1. Wing Base (RD-ST-WF-304)

The Wing Base is a small (4.25 x 1.0 x .125) detailed part used to form a mounting for the wing on the Center Fuselage. There are four Wing Bases required per round. The designer initiated material selection is aluminum alloy 6061-T6. This is a standard structural aluminum alloy and is readily available in large quantities at reasonable rates. The Wing Base itself is a fairly simple part in design. The required tolerances are conducive to high rate production methods with the exception of the placement tolerance -.003, -.000 called out in two places on the drawing.

The production operations considered for high rate fabrication of the Wing Base were powder metallurgy, permanent mold casting, die casting, and investment casting. The results of the Process Capability Analysis indicated that die casting will be the most economical production method for this part procurred in the required quantities. It should be noted that die casting and investment casting can produce the part in near net shape, with the ream and countersink operations not being required. The milling operation needed to obtain the tolerance listed above will be required with all processes. The recommended material for this case is aluminum alloy 356-T6. Al 356-T6 is a castable alloy comparable in cost and physical properties to Al 6061-T6.

2. Center Fuselage (RD-ST-WF-307)

The Center Fuselage section is a fairly large (13.7 length, 5.8 diameter) cylindrically shaped symmetrical part which replaces the Center Section (13218295) in the current TOW design to form the midsection of the missile and provides the location for wing attachment. The part is a thin wall shape with an inconsistent inside diameter. There is an indented section in the forward end of the part to allow the folded wings to remain relatively flush with the missile's outer skin. The designer initiated material selection was Al 6061-T6, again an excellent selection for the prototype production environment.

The production operations considered for high rate production of the Center Fuselage were permanent mold casting, centrifugal casting, die casting, and investment casting. The die and investment casting processes will produce the required dimensional accuracy and surface finishes, but these processes present the economic disadvantages of high touch labor and processing costs (investment casting), and extremely high die design and fabrication costs (die casting). The permanent mold process will cause high processing costs and require extensive machining expense. The centrifugal casting method was chosen as most economical due to the relatively low processing costs, durability of the dies, and applicability of the process to shapes similar to the Center Fuselage. Fabrication of the Center Fuselage by this method will require additional machining, but this function can be quickly and economically performed with the aid of Computer Numerically Controlled (CNC) machinery.

3. A-3 Clip

The A-3 Clip is a very small, precisely dimensioned metallic bracket used to attach the wing to the Center Fuselage. The part, as designed by JPL personnel, is fabricated from 17-7 PH steel. The clip has numerous tight angles and contours which are required in order to obtain proper wing movement both during assembly and launch. There are eight clips required per round.

The production processes investigated for high rate manufacture included stamping, die casting, investment casting, permanent mold casting, and powder metallurgy. The Prototype Engineering Division of SEPD currently uses a mold and brake press with which to form prototype clips into shape. The parts are then machined to obtain dimensional accuracy. While this operation is an excellent choice for prototyping and limited production runs, the high production quantities that would be required in AATAC production call for a manufacturing method repeatability and speed. For these reasons, die casting was chosen as the most economical production method for the projected production quantities. Die casting provides the highest level of dimensional accuracy and process repeatability while providing a very low processing cost. Die casting is not without its drawbacks. The mold design and fabrication costs for this process will be very high and the mold durability will be degraded by the extreme temperatures required to cast 17-7 PH, but these costs will be spreadout over a very large production quantity.

4. A-3 Wing

The A-3 Wing was designed for the AATAC program by JPL personnel. The wing is a pocket of formed 17-7 PH steel which has a small "doubled" section of material on each side. The wing has small slots through which the clips are used to attach the wing to the Center Fuselage. The wing is designed so as to utilize the physical properties of the material to cause the wing to open and hold shape during flight.

The prototype wing fabrication is being performed by JPL. The methodology used in wing manufacture is as follows:

a. The 17-7 PH steel is purchased in sheet form and in the annealed condition.

b. JPL uses a preprepared blank to shear the 17-7 sheets into the shapes required for the wings and doublers.

c. The contours of the wing halves and doublers are formed using a small hand operated roll press.

d. The cutout along the bottom (missile body edge) of the wing halves are ground to shape.

e. The wingtip tab is folded with a small break press.

f. The doublers are spot welded to the wing halves.

g. The wing halves (with doublers) are heat treated to the RH950 condition. Contoured metal supports are used to prevent deformation during heat treat.

h. The cusps are flattened using a two-step operation and a small fixture. The cusp flattening operation is a precise procedure which is viewed as the most critical production step. The proper angle must be obtained to allow the release of yield stress to form the required wing shape.

i. The wing halves are attached via the tab. One wing half tip (without tab) is tucked under the folded tab of the other half.

j. The wing halves are flattened together using a fixture, and the halves are spot welded together using small weld placement fixtures as guidelines.

k. The excess wing material is trimmed after welding.

l. The completed wings are cleaned.

5. Synopsis of Recommended High Rate Manufacturing Operations for the A-3 Wing

Due to the unusual mechanical function required of the part shape and its material properties, the production methods by which the wing can be fabricated are limited. Several of JPL's production processes are required to obtain certain material or structural characteristics. This limits the process candidates even further. In order to insure functional integrity in a high rate environment, it was determined that the recommended production alternatives should remain as similar to the JPL fabrication methods as possible.

Several of the methods chosen by JPL are economically feasible (with minor modification) in a high rate environment. The following is a synopsis of the high rate manufacturing operations recommended for wing production:

a. The use of high speed automated blanking equipment to form the wing halves and doublers will provide excellent process economy, and the development of a slightly more elaborate blanking die will allow the blanking of the wing half cutout, thus eliminating the need for the grinding operation currently performed at JPL.

b. The wing and doubler contours, currently formed using a small hand operated roll press, can be formed using a continuously operational medium size roll press with an autofeed mechanism. This method will allow for a great deal of process flexibility with a minimum of operator involvement and associated labor costs.

c. The wing tab folding and cusp forming will be accomplished in much the same manner as current JPL practice. These operations greatly effect the production reliability as well as missile performance and should be performed in a precise manner.

d. The doubler and wing halve welding operations should be automated to the greatest extent possible. The development of detailed patterns and precise fixtures will insure maximum process reliability and repeatability.

e. The heat treat, trimming, and cleaning operations will be performed to the same process specifications currently used, but batch operation will allow for economical manufacture. The heat treat operation will require a cleaning operation prior to heating to remove oil and other impurities. This cleaning will be accomplished by vapor or solvent degreasers followed by scrubbing with a mold abrassive, and rinsing to remove dirt which could cause scale buildup. The parts should be heated to 1400 °F with an electric or radiant gas tube furnace to prevent contact with combusion byproducts. The parts may be precipitation hardened in hydride or nitride salt baths. Scales should be removed by wet or dry grit blasting or vapor blasting.

IV. PRODUCTION COST ESTIMATION

A. Methodology

PED has prepared a production cost estimate for the AATAC wing design. The estimate was prepared using a combination of computer-aided cost analysis techniques developed by PED personnel. These cost techniques were developed specifically for use in analyzing the transition of RD&E Center development programs to the high rate production environment. The algorithms have been used on other RD&E Center programs such as SPIKE, E-M Actuator, and SETTER, and have proven to be quite accurate. The algorithms have been developed using information gathered from various MICOM missile production programs and through interaction with local and regional metal working operations. Information gathered from the ICAM Cost and Design Guide developed by Battelle Laboratories for the U.S. Air Force, was also used in the preparation of the algroithms.

B. Cost Estimates

The cost analysis performed on the AATAC wing design assumed a production rate of 2500 missiles per month (current TOW 2 production rate). The cost estimates were performed using the recommended economical production processes identified as a result of the Process Capability Analysis (reference Section III).

1. AATAC Wing Configuration

The results of the cost analysis indicate that the AATAC wing design can be produced for $185.10 per missile. The cost driver in this production scheme is the Center Fuselage. This part accounts for almost 40 percent of the total fabrication costs. A summary of the AATAC wing fabrication costs is presented in Table 2. Backup cost data for the AATAC wing configuration is contained in Appendix C.

2. Present Wing Configuration

A cost analysis of the current wing configuration (TOW 2) was performed in order to provide information for a comparison of the fabrication costs of the two configurations. The analysis was initiated by gathering TOW 2 historical cost information, machining procedures, and process specifications. The cost data was compiled for parts corresponding in function to AATAC wing configuration parts. The results of the analysis show a cost to the Government of $106.74 for the current wing configuration. A summary of the cost analysis of the current design is presented in Table 3. Relevant backup cost information for the TOW 2 wing is contained in Appendix D.

C. Cost Comparison

A comparison of the fabrication costs of the two alternatives shows a cost differential of $78.32 per round. An item by item comparison of the alternatives reveals that the majority of the increase lies in the Center Fuselage production. The Center Fuselage is longer than the TOW Center Section, but the cost difference comes primarily from the indention on the AATAC Center Fuselage which is used to allow the wings to remain relatively flush with the

TABLE 2. AATAC Wing Design Production Cost Estimation-Summary.

Produced Parts	Material	Prod' Cost	Finish C eration	Finish Cost	Part Cost	No. Parts	T&E Cost	Total Cost
Die Casting:								
Wing Base	A 1356-T6	2.78	3,M	1.69	4.47	4	0.447	18.327
Clip	17-7 PH	3.74	3,Ta	2.88	6.62	8	0.662	53.622
Centrifugal Casting:								
Center Fuselage	A 1356-T6	50.81	D,R,M,T	13.59	64.4	1	6.44	70.84
Wing	17-7 PH	10.32	See List	0	10.32	4	1.032	42.312
Total Cost								165.101

Assumptions:

a. Die life is approximately 40,000 units
b. Production units = 3^,000 rounds per year
c. T&E costs = .10 (Production + Finish) costs
d. Labor rate = $35/hour

Finishing Operations:

D - Drill
R - Ream
T - Turn
M - Mill
P - Plane
B - Deburr
Ta - Tap

TABLE 3. TOW 2 Wing Design Production Cost Estimation-Summary.

Produced Parts	Material	Prod' Cost	Finish Operation	Finish Cost	Part Cost	No. Parts	Source	T&E Cost	Total Cost
Center Section	Al 6061-T	16.9	D,R,T,M,B	11.96	28.86	1	Actuals	2.886	31.746
Wing (10190132)	Al 2024	7.13	-	0	7.13	2	Actuals	0.713	14.973
Wing (10084378)	Al 2024	11.07	-	0	11.07	1	Actuals	1.107	12.177
Wing (10150130)	Al 2024	11.07	-	0	11.07	1	Actuals	1.107	12.177
Wing Lug	3620 St.	7.46	-	0	7.46	4	Est.	0.746	30.686
Wing Spring	-	0.5	-	0	0.5	4	Est.	0.05	2.05
Wing Lock	-	0.75	-	0	0.75	4	Est.	0.075	3.075
Total Cost									106.784

Assumptions:

a. Die life is approximately 40,000 units
b. Production units = 30,000 rounds per year
c. T&E costs = .10 (Material + Production + Finish) costs
d. Labor rate = $35/hour

Finishing Operations:

D - Drill
R - Ream
T - Turn
M - Mill
P - Plane
B - Deburr

missile skin. This indention forces a change in manufacturing method over the TOW configuration, and in fact, dries the selection of a casting method for manufacturing. Machining and finishing costs for the two parts are very similar.

D. Other Cost Considerations

This analysis has dealt with the fabrication and testing costs of the AATAC wing. There is one other cost which should be given consideration in future analyses, and that item is the cost of assembling the two alternatives. The assembly process is quite labor intensive and will prove to be a major cost factor in AATAC production. As a part of this analysis, the assembly instructions and procedures for the current TOW 2 wing were reviewed. This information was compared with probable assembly requirements for the AATAC configuration, and the results of this preliminary comparison indicate that the increased fabrication costs of the AATAC alternative may possibly be offset by lower assembly costs. A more thorough assembly review is needed at such time as the packaging design for the AATAC configuration is complete.

V. IMPACT ON TOW 2 PRODUCTION FACILITIES

PED personnel utilized in-plant SEPD representatives to evaluate the current status of TOW 2 production and evaluate the impact that AATAC implementation will have on current operations. The evaluation centered around three areas: make/buy policies, facilities, and tooling.

A. Make/Buy Methodology

The impact of AATAC production on TOW facilities and equipment will depend largely on the make/buy policy adopted by the prime contractor. For the purposes of this analysis, it was assumed that the make/buy decision would be purely economical. In other words, it is assumed that any fabrication capability required for AATAC production which is not currently available within the prime contractor's facility will be subcontracted to an outside vendor or a sister division of the prime contractor. This approach will minimize the impact on the current production operation and should provide the most economical production alternative. Compliance with this methodology will require the "outside" manufacture of several parts. The center section should be procured from a casting house that specializes in Centrifugal Casting. This will minimize the cost associated with the casting equipment and should lower mold design and fabrication costs. The machining and finishing operations can be accomplished at the prime contractor (as is the case for the current center section). The wing base and clip should be cast by a Die Casting vendor. The finishing operations required for these parts can be accomplished either in-house or by subcontract.

B. Facilities

The evaluation of the floor space and physical plant of the TOW 2 production facility identified the current building and area as adequate to support the modifications required to support AATAC production. The assembly areas appear to be of adequate size to support AATAC wing and center structure assembly operations. Only minor changes will be required in the assembly line flow. The impact of electronics assembly process changes that will result from AATAC incorporation will require some slight modifications to the electronic assembly areas, but the impact will be minimal and changes can be incorporated with only slight expense. The drawing in Appendix E shows the current facility layout.

C. Tooling

The evaluation of the tooling requirements centered around the manufacturing equipment necessary to produce and assemble the modified wing structure. The tooling required will include automated blanking equipment, multiple head spot welding equipment, and a break form press. The equipment is not all currently available at the prime, and it suggested that the subcontracting of wing fabrication to a vendor that is currently utilizing this type of equipment be considered as the tooling costs associated with this type of fabrication will be significant.

The other tooling required to implement AATAC manufacture is basically modified TOW tooling. The handling equipment will have to be modified to incorporate the changes in missile size resulting from using the AATAC fuselage. This modification could result in moderate costs due to the large quanties of handling equipment required to support the production rate. Additional fixturing equipment will be required to support the different wing assembly method, but the costs will not be significant. The current TOW Center Section requires extensive machining and finishing operations which are performed on CNC machining equipment. This equipment can be utilized to support AATAC production.

The TOW test equipment can be used with minor modifications to the fixtures and software.

VI. CONCLUSION

A. Recommendations

The following paragraphs outline suggested areas for future study.

1. Center Fuselage

The Center Fuselage as proposed in this report would be centrifugally cast with slots and cutouts included in the casting. This procedure leaves the job of placing, drilling, and reaming the numerous holes. Future study efforts should center around investigation of state-of-the-art Centrifugal Casting in order to determine the feasibility of casting the holes. This procedure, while increasing the cost of the mold, could provide a substantial (15-20 percent) decrease in part fabrication cost.

2. Assembly Procedures

A detailed study of the assembly methods and fixtures needed for AATAC production is recommended. As previously stated, the assembly costs can be substantially altered by minor modifications in the product design, and significant cost savings could be realized.

3. Spreader

The current AATAC configuration does not include a spreader. The spreader is a fairly simple part in design and will have only a minor impact on AATAC fabrication costs if used. However, the wing/spreader assembly could become a selective assembly procedure, and using the spreader could substantially increase assembly costs.

B. Planned FY 87 Efforts

Follow-on producibility studies for the AATAC are planned. Planned FY 87 efforts include an indepth analysis of the fuselage modifications. The FY 87 study will utilize a similar methodology to determine the most economical fabrication materials and methods for the Forward Fuselage Extension and Splice Ring, and a precision casting study of the Center Fuselage (as outlined above) will be conducted. Planned FY 87 work also includes a review of component selection, mounting, and assembly methods for the electronics items repackaged as a result of the center structure redesign. PED will also review designs of spreaders (or parts which perform the spreader function) which may be considered for AATAC use in order to analyze the impact of design incorporation on AATAC cost and producibility.

VII. SUMMARY

The AATAC wing design is producible in its current form. No major design modifications to improve producibility are required. Several material substitutions to utilize high rate production processes have been suggested. The materials used in the design are readily available at competitive prices.

The incorporation of the AATAC configuration into the TOW 2 production environment can be accomplished with ease. No brick and mortar facility modifications will be required, and a competitive make/buy strategy will ensure the lowest possible production prices and maximum utilization of equipment and facilities currently in use for TOW production.

The AATAC wing fabricaton costs are comparable to the costs for the fabrication of th TOW 2 wing. Cost analyses have shown an expected increase of less than $80 per missile in fabrication costs. Future assembly cost studies could close the price differential gap.

PED will continue to support the Structures Directorate by performing producibility studies on other AATAC components and design changes in an effort to ensure the lowest possible AATAC production costs and the most producible AATAC system.

PART TWO

FY 87 - SECOND YEAR REPORT

I. INTRODUCTION

As the second of a two-year production task, Production Engineering Division (PED), System Engineering and Production Directorate (SEPD), Research, Development, and Engineering (RD&E) Center was directed by the Structures Directorate to isolate producibility efforts on the development of the wing design in the AATAC Flex-Wing program. This second year study assesses the fabrication, cost and material selection of the wing and provides detailed documentation of the results.

A. Problem Statement

The specific tasks identified by the Structures Directorate include the following:

1. Estimate production costs of the flex-wing based on current method of fabrication for 24,000 sets of flex-wings per year, and a total of 250,000 sets.
2. Review in detail the AATAC Flex-Wing structural drawing, for possible ways to reduce production costs using the current fabrication methods. Consult with Jet Propulsion Laboratory (JPL), and Time and Materials (T&M) contractor, to suggest ways of improving the current method of manufacturing.
3. Investigate different flex-wing manufacturing methods, estimate costs, and compare all methods for cost effectiveness and production repeatability.
4. Assess the impact of using different materials, for the flex-wing on production methods and costs.
5. Provide the Warhead and Fuze Function a technical report, on the resul s of the two-year producibility study by SEPD, on the AATAC Flex-Wing and missile.

B. Methodology

The second year producibility effort for the AATAC wing design was conducted in-house by PED. This study also was supported by Machine Craft (T&M contractor) and Jet Propulsion Laboratory (JPL). The cost analysis was performed using algorithms developed by PED. Material prices and manufacturing equipment information were obtained through private enterprise contacts. The University of Alabama in Huntsville Library and Redstone Scientific Information Center (RSIC) were also referenced as information sources.

II. CURRENT FABRICATION

The JPL issued a Flexible Wing Manufacture and Assembly Procedure as a guideline for the current fabrication of the AATAC Flex-Wing. These guidelines coupled with fabricating methods obtained from the T&M contractor, Machine Craft, are presented as a workable model for the current AATAC fabrication method. The following is a list of those combined guidelines, along with descriptions of each step and machinery and processes necessary in each step to manufacture the AATAC Flex-Wing:

A. Mill Anneal Sheets of Material at 1950 °F $\pm$ 25 °F to Reach Condition A

"Annealing of steel is a heat-treating process in which the steel is heated to some elevated temperature, normally in or near the critical range, is held at this temperature for some period of time, and is then cooled, usually at a slow rate to change physical properties. Annealing is employed, in this case, to soften steel for machining, cutting and stamping processes" [1]. "Heat-treating can be accomplished with various kinds of furnaces; gas, oil or electrically heated furnaces are available" [2]. For estimating purposes, oil heating for the furnace power source is assumed. The annealing process is a time-consuming task, but actual cost drivers are linked to the setup and handling time (loading and unloading the sheets of steel from the furnace) and not the annealing process itself.

B. Machine and Form to Dimensions Per Figure 3 of Drawing RD-ST-WF-336 for A-4 Wings (Appendix G)

A blanking process is currently being used by Machine Craft to machine and form the wing halves. "Blanking is a shearing operation in which a die is configured to specified dimensions and used to stamp shapes from solid sheets of metal" [3]. Blanking is a semiautomated process and cost drivers consist of tooling cost, handling time and setup time.

C. Fold Tab at Wing Tip to a Minimum Bend Radius of 0.024 Inches (150 percent skin thickness)

A press brake is currently being used by Machine Craft to fold the wing tabs. "Press brakes are used to brake, form, seam, trim, and punch sheet metal. They have short strokes and are generally equipped with an eccentric type of drive mechanism. Conventional power press brakes may be either hydraulic or mechanical" [4]. Press brakes are semiautomated and cost drivers consist of tooling cost, handling time and setup time. Using a hydraulic press brake, Machine Craft folds the wing tab to a 90° angle and leaves the tab in this state until the spot weld'ng of the wing halves occur.

D. Clean Parts in Sonic Cleaner with M50 Solution for 30 Minutes

The cleaning process is necessary to remove impurities from the surface of the material. This process occurs twice in the production process of the AATAC Flex-Wing. The first time, the wing parts are cleaned to prepare for the spot welding of the doublers. The second time, the wing parts are degreased to prepare the part for heat treating. An advantage to this process is multiple parts may be cleaned at one time and monitoring is not necessary. Therefore, the cost driver consist mainly of handling time.

E. Spot Weld Doublers to Wing Halves per Pattern in Figure 2 of Drawing RD-ST-WF-336 for A-4 Wings (Appendix G)

From information obtained from JPL, the spot welding process is one of the more crucial steps in the AATAC wing assembly. Because of the heat generated by the resistance welding process and the small scale at which the welder is working, extra care in the design and the welding stages are needed. Spot welding, or resistance welding, is a joining process in which high current flow is generated by electrodes, when contact is made, and this current is allowed to pass between two pieces of securely clamped metal. Heat being generated by the electrodes create a joining process or a weld. A key factor in the spot welding process is fixturing or the clamping process. A good weld is not obtainable without good contact between metals. Current specifications recommend electrode pressure to be 10 pounds. Spot welders compared to most manufacturing machinery are very inexpensive. Fixturing and handling times are key cost drivers, but these can also be lowered by automation. Machine Craft is currently using a hand held Miller spot welder.

F. Deburr All Parts

"Blanking operations often leave sharp, and possibly dangerous, edges that cannot be removed in the cleaning process" [5]. These sharp edges must be deburred. Currently, Machine Craft is using a hand deburring process which consist of manual elements. The anticipated deburring operation for full scale production is loose-abrasive deburring. "Loose-abrasive deburring is a controlled method to remove burrs. Parts to be deburred are placed in a vibrating tub with an abrasive media, water or oil, and perhaps some chemical compound. As the tub vibrates, sliding motions of the media cause an abrading action. Abrasives are usually aluminum oxide and silicon carbide and exist in a preform geometry" [6]. Loose-abrasive deburring eliminates most of the manual labor involved in this deburring process, but handling time is a key cost consideration along with the machinery investment.

G. Shape and Form Wing Halves to Figures 6 and 7 of Drawing RD-ST-WF-336 for A-4 Wing (Appendix G)

This operation introduces a curvature to the flat blanked wing halves. JPL has used a hand rolling technique to accomplish this task in the past, but this method must be interchanged with a more automated operation in order to lower corrosion cracking and production cost due to excessive handling. One solution to the handling problem is the use of a press brake machine. Presently, Machine Craft is using a press brake machine to bump the curvature into the wing half. The bumping occurs in more than sixty isolated spots across the width of the wing half. A small amount of handling is still required, but a majority has been replaced. Refer to Step 3 (Folding of Wing Tab) for a description of the press brake.

H. Clean Material by Vapor Degreasing and Alkaline Cleaning Processes in a Protective Atmosphere or Vacuum

This operation prepares the wing halves for the heat treating process (Step 9). "Vapor degreasing is a metal chemical cleaning process that introduces fresh chlorinated solvents onto a contaminated surface on a continuous basis. Therefore, not only is the solvency action at a maximum, but any retained solvent will have a minimum residual oil concentration and will leave the lowest possible residue on the surface of the parts being cleaned" [7]. "The parts are lowered into a tank in which the solvent has been heated to its boiling point causing the solvent to vaporize. As the hot vapors meet the cold parts, the vapors condense and dissolve the dirt" [8]. Alkaline cleaners are particularly effective in soak tank operations. "Soak tank cleaning solutions comprising caustic soda, soda ash, phosphate, silicate, and wetting agents are commercially available. The parts to be cleaned are immersed for a period of 5 to 20 minutes, water rinsed, and dried prior to additional operations. Both vapor degreasing and alkaline cleaning are more suited to batch work than to continuous processing because of the dwell time" [9]. This fact leads to cost savings in high rate production, but handling time is still a producibility consideration.

I. Heat Treat Wing Halves Using a Mild Steel Contoured Support to Prevent Sagging. The Wing Halves will be Austenite Conditioned, Martensite Transformed and Precipitation Hardened.

1. Austenite conditioning. Heat to 1750 °F ± 15 °F for 10 minutes; air cool to condition A-1750.

"Heating a condition A material in the austenite conditioning range results in removing carbon from the solution in the form of chromium carbides. Fewer carbides, though, are removed at 1750 °F than at a temperature of 1400 °F" [10].

2. Martensite transformation. Cool within 1 hour to -100 °F ± 10 °F; hold for 8 hours to reach condition RH-100.

"Removal of the carbon and chromium from the austenite matrix makes the austenite unstable and, upon cooling, results in transformation to martensite. Accompanying this phase transformation is a substantial increase in magnetic permeability and a dimensional expansion of about 0.0045 in./in. In the martensitic condition, the aluminum in the 17-7 PH steel is in supersaturated solid solution" [11].

3. Precipitation hardening. A-4 wing - heat to 950 °F ± 10 °F; hold for 1 hour and air cool to reach condition RH-950.

"Upon heating for precipitation hardening, the aluminum in the martensite is precipitated as Ni-Al intermetallic compound. The precipitation-hardening treatment has two functions: (1) it stress relieves the martensite for increased toughness, ductility, and corrosion resistance; and (2) it provides additional hardening by precipitation of the intermetallic compound (Ni-Al)" [12].

The overall purpose for this heat treating process is to restore strength to the wing halves. This process is complex, but as mentioned in Step 1 (Annealing), the specific heating operation is immaterial to cost estimating, "the driving cost during production is the handling time" [13].

J. Wing Assembly

1. Flatten the cusp area of the lower wing half (with tab) by flattening the central, gently curved section of the wing half and hold in fixture.

2. Tuck upper wing half (without tab) under folded tab of the bottom wing half.

3. Flatten cusp of upper wing half.

4. Clamp chord lengths together and spot weld per Figure 1 of drawing RD-ST-WF-336 for A-4 wing, (Appendix G).

Substeps J.1 through J.4 are all performed by Machine Craft using a hydraulic press brake and a Miller spot welder. The press brake eliminates handling (corrosion) and time lost for fixturing. The spot welder is a replacement for the UNITEK 125 machine which yielded the best results at JPL. Also, with the introduction of the press brake, Machine Craft expects some angling modification to be performed on the spot welder electrodes. Refer to Steps 3 and 5 for detailed information about the press brake machine and the spot welding process.

5. Trim the assembled wing to dimensions per Figure 5 of drawing RD-ST-WF-336 for A-4 wing (Appendix G).

In this process, excess material is removed from the wing by a cutting or grinding operation. This extra material is necessary because it is used in the clamping operation for leverage and also serves as a guide to position the clamps. Machine Craft proposes to machine off the waste material. This process will incorporate a milling machine. "Milling machines are semi or fully-automatic and have several distinctive features: automatic cycle of approach cutter and work relative to each other; rapid movement during noncutting part of the cycle; and selective spindle stops and speeds. After the machine is setup, the operator is required only to load and unload the machine and to start the automatic cycle" [14]. This advantage lowers production costs.

III. PRODUCTION COST ESTIMATION

PED has prepared a cost estimation for the AATAC Flex-Wing. The estimation is based on the current method of fabrication at JPL, with high rate production inputs from Machine Craft, for 24,000 sets of flex-wings per year.

A. Methodology

Information compiled for this report was obtained via Methods Time Measurements (MTM) techniques, standard macrodata timetables, cost estimating manuals used by machinists, and Computer-Aided Production Engineering (CAPE) techniques developed by PED. Information and algorithms obtained or used in the first year report are also referenced.

B. Definition of Methods

MTM techniques are estimates of individual body movements. For instance, to estimate the time to lift a glass of water to one's lips, MTM techniques considers the time to: reach, gain control, and lift the glass of water. Time values are assigned to each step, based on weights and distances, and a total time is determined when added together. Standard macrodata timetables and cost estimating manuals used by machinist are a compiled list of representative times to perform specific tasks. These tables and manuals are not detailed like MTM techniques. Given specific characteristics for the process of lifting a glass of water, the timetables and manuals list a total time for the operation. Computations, usually, are not necessary, but occasionally, assumptions must be made. CAPE techniques are producibility engineering algorithms, derived from previous documented reports by PED engineers, installed onto computers in spreadsheet form. "These algorithms have been used in programs such as SPIKE, E-M Actuator and SETTER;" and prove to be accurate due to past experiences and constant updates [15].

C. Cost Estimate Overview

For estimating purposes only, the current fabrication method used in the development of the AATAC Flex-Wing is presented in this report in ten steps. Detailing the fabrication method in steps should create a more accurate report, help make the fabrication process easier to follow, and give the Warhead and Fuze Function a comparison to last year's report. Using algorithms and man-hour time tables, each step is analyzed based on equipment cost, material handling time and setup time. These operations are represented in cost per hour, and a $35 multiplier is used. This hourly rate takes into consideration the average labor cost, overhead, and profit experienced by private industry. A total cost estimate per wing is determined and presented as the sum of the Recurring Cost (RC) and Nonrecurring Cost (NRC). RC's are operating expenses, such as, the time required to stack wing halves after blanking; NRC's are initial or startup expenses, such as, the cost for a die used in the blanking operation.

1. Material

Purchase Material

Telephone calls were made to local contractors to obtain a price per sheet for 17-7 PH stainless steel - condition C. The sheet forms are of dimensions 36 in. x 120 in. x .016 in. and the weight per sheet is 20.16 pounds. The best price available, assuming a purchase of 5 sheets, is $100.55 per sheet. (A 42.5 percent markup is included in each price in order to compensate for private industry's charges for handling, overhead, and profit.) Assuming a purchase of 500 sheets, a total cost per sheet of $79 can be acquired. AMI in Nashville, TN, furnished this cost information. Other sources were consulted and gave similar cost data. Next, a total number of wing sets per sheet were determined to get this price in terms of cost per wing. A wing set consists of two wing halves, two doublers, and two wing clips. The total volume of one wing set is approximately 0.8 cubic inches (this includes a 12.5 percent scrappage allowance). This volume divided into the volume of the sheet (69.12 cubic inches) yields 86 wing sets. Therefore, the price of the material per wing is $0.92 assuming a production of at least 43,000 wings.

Mill Anneal to Condition A

Assumptions: A 250 day work year and a production rate of 4.5 sheets annealed daily is assumed to meet the 96,000 annual wing rate. The annealing rate could be much faster but the overall production rate could not keep up. Only one furnace is needed for this operation, and it will be setup once daily.

The purchased sheets of 17-7 PH stainless steel are mill annealed to condition A. Using macrodata timetables [16] the RC is estimated to be $0.0088 (rounded to $0.01) per wing. This estimate is based on the time to load and unload the sheets of steel from a furnace (1.3 minutes per sheet). The cost drivers are the weight and size of the sheets. NRC is estimated to be $840 over the production life. This is based on a setup time of 6 minutes each day. At 250 setups a year, this cost is equivalent to $0.00875 (rounded to $0.01) per wing. Thus, the total annealing cost per wing (RC + NRC) is approximated to be $0.02.

2. Machine and Form

Blank Wing Halves

Assumptions: Only one blanking machine is needed in this operation. Two setups will occur daily over the production life.

In determining the cost to blank one complete wing, two methods were used: (1) algorithms developed by PED engineers, and (2) standard data timetables. Each method approaches the blanking process differently, but yielded results that are similar. In order to benefit from both methods, an average of each result is determined and presented as the final estimated price.

PED algorithms are presented first. Assuming a production rate of 7.5 wing halves per minute, and 5 percent, 6.67 percent and 5 percent fatigue, rest and learning curve factors, respectively, are present, the estimated RC per wing half is $0.083. The die cost and setup time are the two cost drivers in the NRC estimation. Calculations yield the respective die and setup costs as $6,895.94 and $530.97 annually. The die cost is based on a die box dimension of 16.112 inches and the setup time is derived from 6.67 percent of the total operating time in the blanking process. The total annual NRC is $7,426.91, or $0.039 per wing. The total cost estimate is $0.24 per wing for this blanking process.

The second estimate utilized standard macrodata timetables [17]. To use the tables, a box dimension of the blanked pieces must be calculated. A blank size of 10 inches was measured. The total time to blank, stack and handle each wing part is calculated to be 0.141 minutes, or a RC of $0.083. Next, a blanking setup time is needed to determine the NRC. From the data tables, a time of 0.65 hours is assigned. With a total blanking production life of 28.2 days, 56.4 setups will be performed annually. This is equivalent to 36.66 hours or $1,283.1 over the annual production life. Therefore, the NRC per wing part is $0.007. The total cost estimate per wing is $0.09, or $0.18 per wing for this blanking process.

Averaging the blanking estimates ($0.24 and $0.18) resulted in a total cost of $0.21 to blank two wing halves.

The blanking process for the doublers is the same as that of the wing halves. The same methods and assumptions used for Section III.C.2, also apply in this section. The results of the PED algorithms and macrodata timetables yielded $0.18 per wing and $0.14, respectively, per wing. The average of these methods is $0.16. Thus, the per wing cost to blank the doublers.

3. Fold Wing Tab

Assumptions: Only one press brake is needed for this operation and setups will occur twice daily.

Folding the wing tab is a prerequisite to the wing half welding process. Using macrodata timetables [18], the total time to stack, position and fold a wing tab is estimated to be 0.12 minutes. This price is based on a 10-inch box dimension of the wing half and a 4-inch lip width of the tab. The RC per wing is determined to be $0.07. The NRC is derived from the setup time and the tables assign 0.3 hours. At 0.12 minutes per tab, 500 wing tabs can be folded every hour or a total production life of 24 days. This time translates into 48 setups annually. Therefore, a total NRC is $504 per lot or $0.005 per wing and the total cost estimate to fold one flex-wing tab is $0.075.

4. Cleaning (preparation for spot welding)

Assumptions: No setup time will be needed for this operation and the parts to be cleaned will be placed in an 8-in. x 18-in. x 60-in. basket prior to submersion into the M50 solution. Also, 10 man-hour minutes will be assumed lost while waiting for the parts to soak. A total of 384 wings will be cleaned daily; this rate coincides with the annealing operation.

The size of the holding basket (8640 cubic inches) can contain the volume of 384 wings (273 cubic inches). Therefore, the cleaning process can be completed in a single operation. The time to load and unload the basket is the main consideration in the cost estimate. Using macrodata timetables [19], an estimated time of 2.8 minutes to clean a basket of 2304 wing pieces is determined. With an addition of 10 minutes for waiting time, a total labor time for this operation is estimated to be 12.8 minutes. This time is equivalent to $7.50 daily or a cleaning cost of $0.02 per wing set.

5. Spot Weld Doublers

Assumptions: Currently, very little automation is being implemented in this step. At least eight spot welding machines will be needed to keep up with a daily production rate of 384 wing sets and one setup for each welding machine will occur daily.

Macrodata timetables are referenced in this section [20]. Using a 10 and 4-inch box dimensions for the wind and doubler, respectively, the handling time is evaluated to be 0.47 minutes. Fifty-seven spot welds are necessary in this welding process and the tables allow 4.2 seconds per weld, or 3.99 minutes to spot weld the doublers. The total RC time for this process is 4.46 minutes or a RC of $2.60 per wing half or $5.20 per wing. The NRC is calculated based on the setup cost and the timetables assign 0.3 hours. With eight machines setup daily over a 250-day production life, a total setup time of 600 hours would be necessary annually. This time is equivalent to an annual man-hour labor cost of $21,000 or a NRC of $0.22 per wing. The total doubler spot welding cost is $5.42 per wing.

6. Deburring

Assumptions: Loose-abrasive deburring will be used, only one machine is needed and the machine will be setup once daily.

The volume size of each deburred piece is needed to determine the RC. The volume for the wing half with doubler and wing clip is 0.3564 cubic inches. Using the microdata timetables [21], and considering handling, washing, oil dipping and handpick disposing steps, the combined RC time to debur each wing half is 0.08433 minutes. Therefore, the RC to debur a wing half with doubler and a wing clip is $0.049 or $0.10 per wing set. The data tables assign 0.1 minutes for setup time. Therefore, the total NRC time is 809.28 minutes over the production life or a NRC of $0.005 for the deburring process. Thus, the total deburring cost per wing set is $0.105.

7. Shaping Wing Halves

Assumptions: A press brake machine will be used to introduce the curvature to the wing halves, nine machines will be needed to keep up a production rate of 384 wing sets daily and one setup per day for each machine will be required.

A box dimension of the wing blank and length of the area to be bumped, 10 and 6.5 inches, respectively, was determined and reference to the macrodata timetables is made to estimate the shaping cost. The RC is comprised of the bumping and stacking times. Machine Craft isolates 60 bumps per wing half, therefore, a time of 0.09 minutes per bump yields a total bumping time of 5.4 minutes. A stacking time of 0.03 minutes per wing is assigned. The total bumping and stacking times equal 5.43 minutes per wing half. The RC per wing is $6.34. The NRC is the setup cost of nine press brake machines. A time of 0.3 hours per machine is assigned for daily setup. A total production life setup time is calculated at 675 man-hours. Therefore, the total NRC is $23,625 over the annual production life, or $0.25 per wing. The estimated production cost for the shaping operation is $3.29 per wing half or $6.59 per wing.

8. Cleaning (preparation for heat treating)

1. Vapor Degreasing

Assumptions: Only one cleaning machine is needed in this operation, and a setup time is not necessary.

Multiple part cleaning is possible in this operation; the macrodata timetables [22] assign times for vapor degreasing based on part size. The flex-wing box dimension is determined to be 30.2 inches. A time of 0.085 minutes per wing set is assigned. Therefore, the total vapor degreasing operation is equivalent to $0.05 per wing.

2. Alkaline Cleaning

This operation is the same as III.C.8. A total cost of $0.02 per wing set is estimated.

9. Heat Treating

Assumptions: Wing parts are loaded and unloaded from fixtures and furnaces by hand; two furnaces are needed to maintain daily production rate of 384 wings, and one setup is necessary daily for each furnace. Also, the wing parts will remain in the furnace for the duration of all three substeps (austenite conditioning, martensite transforming and precipitation hardening) in the heat-treating operation, and, therefore, the parts will be transported to and from the furnace only once.

The wing half is calculated to be 0.36 cubic inches and used with the macrodata timetables [23] a total time of 1.41 minutes per wing half is estimated for the heat treating process. This time includes 0.23 and 1.0 minutes to load and unload a part to and from a fixture, and a fixture and part to and from the furnace, respectively. Additionally, 0.18 minutes is included for protective clothing preparation. From this time the RC is calculated to be $1.65 per wing. The timetables assign a setup time of 0.1 hours daily. With two furnaces operated over a production life of 250 days, the total production cost for setups is $1,750. Therefore, the total NRC for this operation is $0.02 per wing. Thus, the total heat treating cost per wing is $1.67.

10. Wing Assembly

Flatten Cusp

Assumptions: One press machine is used in this operation, this machine will make it possible to incorporate several substeps at one time. Only one setup per day over the production life is necessary.

A box dimension of 10 inches is used, along with, macrodata timetables [24] to determine a production estimate. The times calculated for each step in this operation are as follows: time to flatten bottom half of cusp is 0.37 minutes, time to tuck upper wing half under wing tab is 0.21 minutes, and time to flatten and clamp both wing halves is 0.17 minutes. A total time of 0.75 minutes is required for these steps, which is equal to a RC of $0.44 per wing. A setup time of 0.3 hours is assigned for the press brake preparation. This operation has a production life of 160 days. Therefore, a total production cost of $1,680 exist annually for setups. This cost is equivalent to a NRC of $0.02 per wing. The total cost to flatten the cusps is $0.46.

Spot Weld Wing Halves

Assumptions: Six spot welding machines will be needed to maintain the production rate and only one setup daily is needed for the machines. The press brake machine, implemented in Section III.C.10, will do away with handling in this operation.

The wing halves are already fixtured, but a 180-degree rotation time and spot welding time must still be calculated. The macrodata timetables [25] allow 0.08 minutes for rotating and 7.42 minutes for spot welding 114 individual points. A total spot welding time of 7.5 minutes is estimated. This calculates to a RC or $4.375 per wing. A setup time of 0.3 hours is assigned per setup. A total production cost of $15,750 is calculated for six spot welding machines to be setup daily for 250 days. This cost is equivalent to a NRC per wing of $0.16. The total cost to spot weld two wing halves is $4.54.

Trimming

Assumptions: One milling machine is needed for the total trimming operation, the wing halves are already fixtured (Section III.C.10), and one setup is required daily over the production life of the trimming operation.

Stacking, rotating, machining, and cleaning steps are all encompassed into the trimming operation. From macrodata timetables [26], the estimated time to perform each of these steps is as follows: 0.03 minutes for stacking, 0.06 minutes for rotating the wing, and 0.07 minutes for cleaning. The machining step requires a total time of 0.15 minutes and is derived from 0.06 minutes to start and stop, 0.04 minutes to reverse, and 0.05 minutes to spindle back the machine. The total trimming operation is 0.31 minutes or a RC of $0.18 per wing. An estimated time of 0.5 hours is required per setup for the milling machine. With a production life of 66 days, the total setup cost incurred over the production life is $1,155. This cost is equivalent to a NRC per wing of $0.01. Therefore, the total trimming cost per wing is estimated to be $0.19.

11. Production Cost Estimation Summary

A summary of the production cost estimate is presented in Table 4.

IV. DRAWING REVIEW

PED performed a tolerance analysis in reviewing the AATAC Flex-Wing structural drawings for possible ways to reduce production costs using the current fabrication methods. PED also consulted with Bob Bamford, JPL, and Norm Esslinger, Machine Craft, for ways to improve the current method of manufacturing. The results were as follows.

A. Tolerances

The first step of the tolerance analysis was to confirm that the manufacturing processes recommended could meet the tolerance requirements. The rules and calculations used for this analysis can be found in Appendix H. The tolerances from Drawing No. RD-ST-WF-337 (Appendix G) are $\pm$ 0.5 °F for angles, $\pm$ 0.005 inches for dimensions with three decimal places, and $\pm$ 0.02 inches for those with two decimal places.

For the blanking process, a tolerance of $\pm$ 0.005 inches is practical. Therefore, blanking can be used without any additional processes, such as grinding, to meet the tolerance requirements. The placement of the holes and slots meet blanking constraints, and the sizes of the hole, slots, and tab are achievable with blanking.

A tolerance of $\pm$ 0.005 inches is practical for most forming processes, including hydroforming and the Guerin process. (These processes will be discussed in Section V.A.3.) It should be noted that the tolerances for the angle and radius of the inner bend allow for an arc length with a tolerance of $\pm$ 0.03 inches, which is looser than desirable. The reference dimensions, hr and Wr (Appendix A, Figure 3: Formed Root-End Section of Wing-Halves), are necessary to control the arc length.

PED's conclusions from this analysis are that the tolerances called out in the drawing are practical, for the manufacturing processes, and there is no reason to loosen them.

B. Manufacturing Changes

While consulting with Machine Craft for improvements in the manufacturing processes, Norm Esslinger, Plant Manager, recommended the process order of the heat treating and spot welding procedures be interchanged. Mr. Esslinger identified the transformation change the heat treated 17-7 PH material goes through during spot welding. The heat generated, from welding, causes the material structure around the spot welding nuggets to change. This change makes the material either brittle or soft; and the transformation is inconsistent. Therefore, future problems may arise and flex-wing applications may be limited. Interchanging the process order and developing a fixture to help maintain the shape of the wing during heat treating will correct this problem.

TABLE 4. AATAC Wing Production Cost Analysis Summary.

Production Rate: 96,000/Yr
Material: 17-7 PH

Process	Recurring Cost/Part	Nonrecurring Cost Annually	Total Cost per Part	Total Cost per Wing	Percent Cost/Wing
Purchase Material	$0.46	$0.00	$0.46	$0.92	4.50%
Mill Anneal	$0.01	$840.00	$0.01	$0.02	0.09%
Blank Wing Halves					
Method 1	$0.08	$7,426.91			
Method 2	$0.08	$1,283.10			
Average	$0.08	$4,355.01	$0.11	$0.21	1.03%
Blank Doublers					
Method 1	$0.08	$1,174.00			
Method 2	$0.07	$1,001.00			
Average	$0.07	$1,087.50	$0.08	$0.16	0.78%
Fold Wing Tab	$0.04	$504.00	$0.04	$0.08	0.37%
Clean (for welding)	$0.01	$0.00	$0.01	$0.02	0.09%
Spot Weld Doublers	$2.60	$21,000.00	$2.71	$5.42	26.51%
Deburring	$0.05	$472.08	$0.05	$0.10	0.50%
Shape Wing Halves	$3.17	$23,625.00	$3.29	$6.59	32.22%
Clean (for heat-treat)					
Vapor Degrease	$0.03	$0.00	$0.03	$0.05	0.24%
Alkaline Clean	$0.01	$0.00	$0.01	$0.02	0.10%
Heat Treating	$0.83	$1,750.00	$0.83	$1.67	8.16%
Flatten Cusp	$0.22	$1,680.00	$0.23	$0.46	2.24%
Spot Weld Wing Halves	$2.19	$15,750.00	$2.27	$4.54	22.23%
Trimming	$0.09	$1,155.00	$0.10	$0.19	0.94%
TOTALS	$9.85	$72,218.59	$10.22	$20.44	100.00%

PED phoned Bob Bamford at JPL to validate Machine Craft's claim. Mr. Bamford agreed to the spot welding material structure change but said that, in his opinion, the change would not warrant any concern. When asked why JPL chose to heat treat the wing halves before spot welding them, Mr. Bamford said it was the easiest procedure for the JPL facility. Mr. Bamford went on to say that spot welding could indeed be performed before heat treating; furthermore, the development of a heat treating fixture would not be difficult to produce. Mr. Bamford could not point out any significant change in the final wing product by interchanging these steps, but did agree that the wing material structure would be consistent throughout, which is a very desirable trait.

A stress Analysis for the AATAC Flex-Wing was performed April 1987 by the Structural Analysis and Design Function group (Appendix I). The analysis found that interchanging the heat treating and spot welding procedures will diminuate the current wing designs load tolerance. Furthermore, the study revealed that the prestresses from heat treating "contributed approximately 25 percent to the wing's load handling capacity" [27]. Therefore, to ensure the best possible performance of the AATAC Flex-Wing, manufacturing processes should conform to those steps and procedures outlined at the beginning of this report.

C. Design Changes

Through consultation with Machine Craft, Stan Dempsey, Marketing Manager, pointed out the need for a design change to the wing half opposite the wing tab. Currently, a tab exists on one wing half and is folded over the mate wing half. Drawing specifications require a smooth flat finish across the top of the formed wing. Therefore, the wing tab base must be flush with the top edge of its wing half mate and the wing tab must be folded at the tab base. The design change is necessary because these specifications are not being met. The wing tab is being folded about 1/3 of the way from its base. In order to obtain the required flushness and proper bend location, the opposite wing half must be undercut by 1/100ths of an inch. This small change should resolve the mismatch of the wing tab and mated wing half. Figure 2 indicates the design change. This change would help meet finished product design requirements, improve wing performance, and could be incorporated into the blanking die with no added cost.

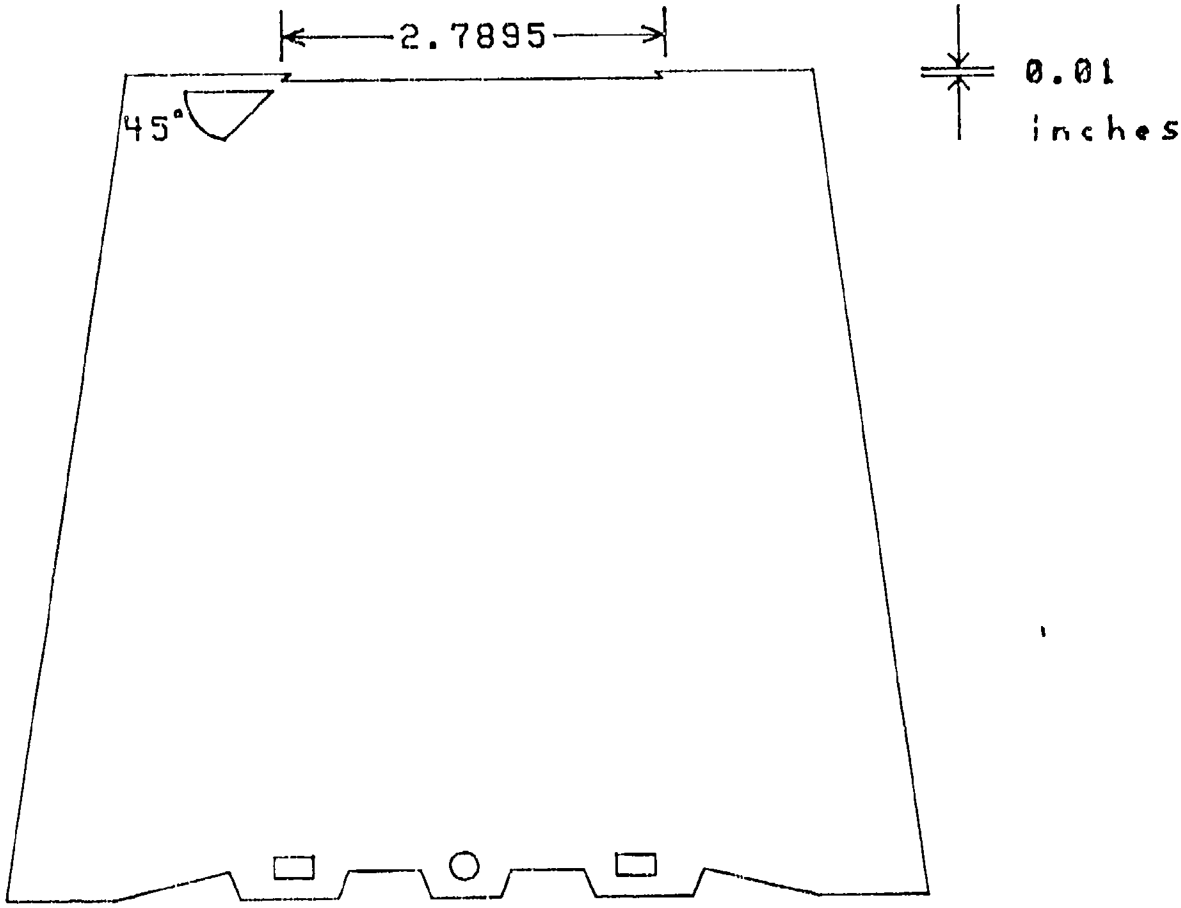


Figure 2. Design change for wing tab folding procedure.

V. MANUFACTURING CONSIDERATIONS

Investigations were made by PED to define different manufacturing methods for the AATAC Flex-Wing. Cost estimates were performed; and comparisons were analyzed based on cost effectiveness and production repeatability. The introduction of new manufacturing processes for the AATAC Flex-Wing fabrication considered final performance of the product, as well as cost advantages. The intention of this report is to demonstrate that the product can be made more producible by increasing production rates, lowering cost and maintaining design and performance criteria.

A. Cost Drivers

The identification of cost drivers is easily made by referring to Table 1. Spot welding and wing half folding steps combine for more than 75 percent of the total manufacturing cost of the wing. If these cost drivers could be lowered by 50 percent, an annual savings of over $790,000 would be realized in the manufacturing process of the flex-wing. These savings would approach $8,000,000 over the 10.5 year production life.

B. Overview

Suggestions as to how to lower production cost for the spot welding and wing half folding steps will be presented in this section, along with, blanking and trimming recommendations for the wing halves and doublers.

1. Blanking

The production rate of the blanking processes is assumed constant. Therefore, the blanking time is independent of the die configuration. PED recommends that a die be designed that will allow the blanking of both the doubler and wing half to coincide. A pattern similar to Figure 3 would suffice.

The recommended die could be developed for $4,000 [28] and an assumption that two would be needed for the annual production life would make the nonrecurring die cost $8,000. The setup time is derived from previous calculations made in the blanking process. The average setup time (using PED algorithms and standard macrodata timetable) is $907.04 during annual production. The die cost added to the setup cost would make the annual NRC $8,907.04. The production rate would be about 7.5 wing halves and doublers per minute (RC of $0.16 per wing). The NRC per wing, $0.09, added to RC makes the total cost to blank a set of doublers and wing halves $0.25. This cost would result in a reduction of $0.12 per wing, a savings of 32 percent.

2. Trimming

As shown in Figure 4, the shaded area is the material trimmed from the wing at the end of the manufacturing process. The material is used as leverage to maintain tension in the wing and serves as a pattern guide in the spot welding process. If the die in Figure 3 was redesigned to the dimensions in Figure 4, the blanking process would incorporate the trimming process and a fabrication step would be deleted. The redesign could be implemented without incurring an additional cost for the die in Figure 3, and $0.19 per wing would be saved.

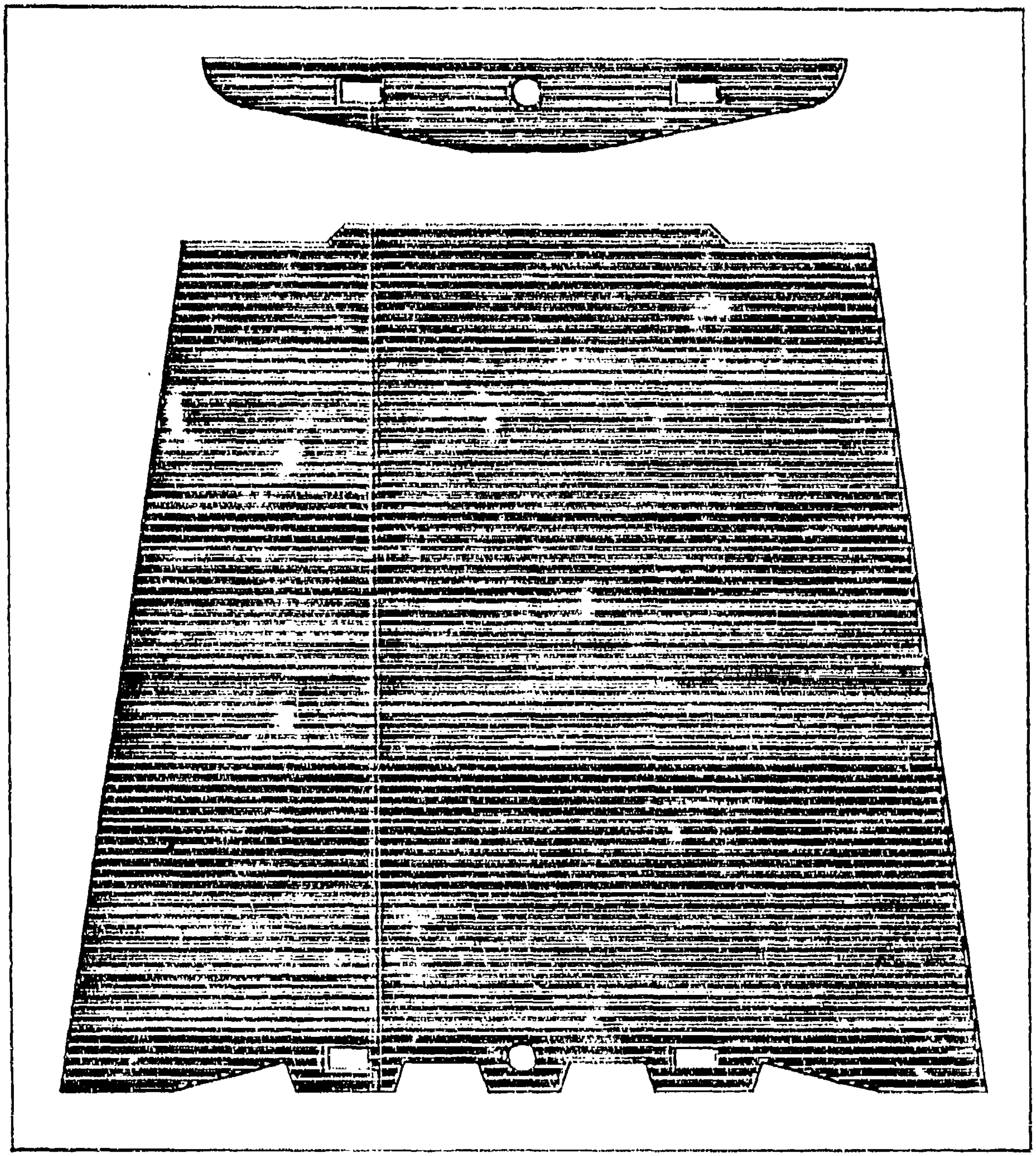


Figure 3. AATAC die configuration, male or raised portion of die.

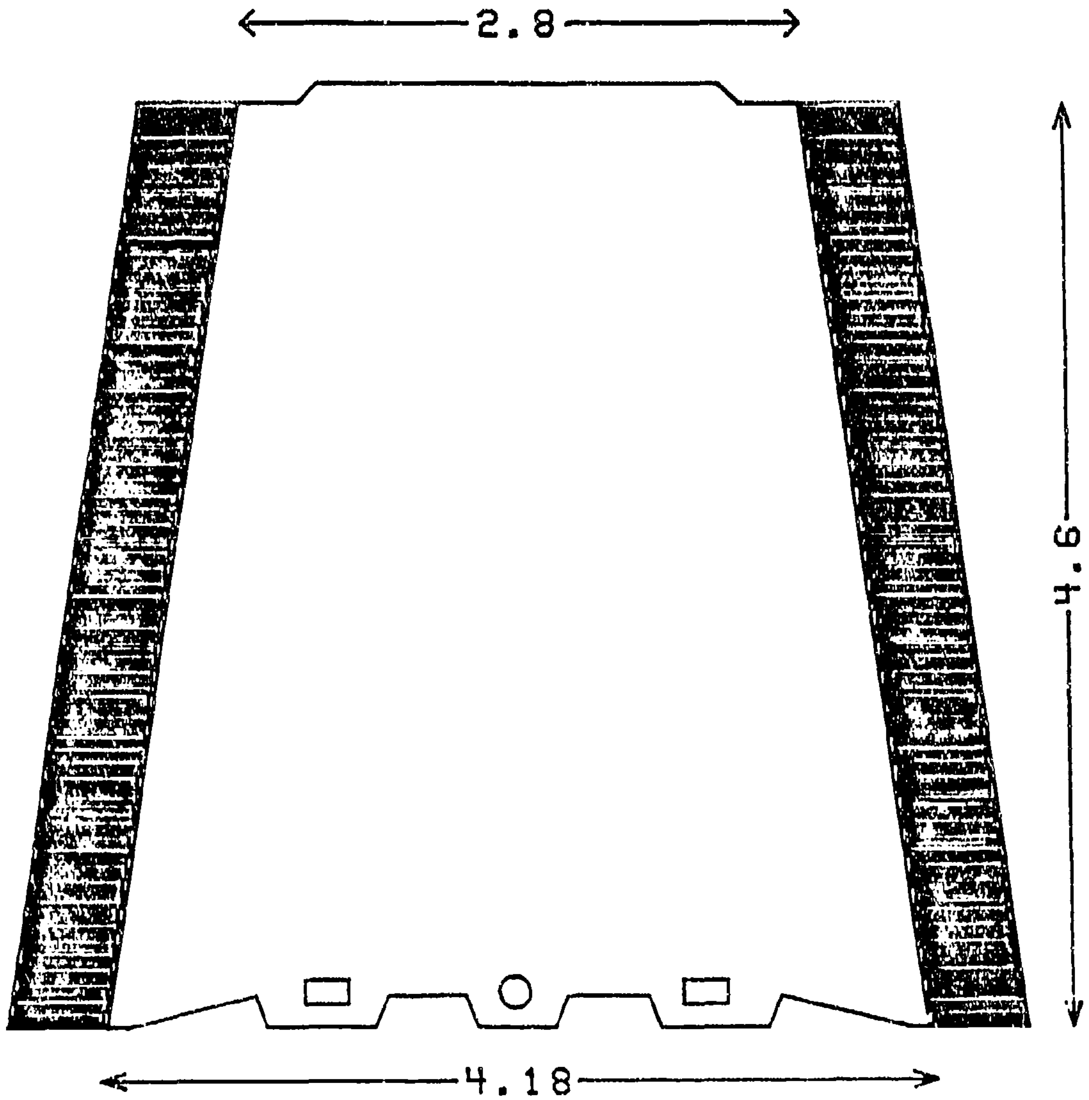


Figure 4. Recommended die size, current waste material to be removed in the blanking process.

With the further development of a fixture clamp that could be driven by a press brake, the absence of the waste material would not be missed. Figure 5 is a configuration for the cover of such a clamp. The wing halves would be held in place by a confining compartment and the cover then would be lowered down to compress the wing halves together. Spot welding would then be performed.

3. Wing Half Shaping

The introduction of automation into this process would lower production cost and material corrosive cracking of material caused by excessive handling. PED recommends hydroforming or Guerin forming be implemented to replace current hand rolling techniques at JPL and press brake machining at Machine Craft.

"The Guerin process utilizes the phenmenon that rubber of the proper consistency, when totally confined, acts essentially as a fluid and will transmit pressure uniformly in all directions. Since no female die is used and form blocks made of wood replace the male die, die cost is quite low" [29]. The hydroforming process uses the same principle as the Guerin process but "replaces the rubber pad with a flexible diaphragm backed by controlled hydraulic pressure" [30]. Refer to Figures 6 and 7 [31]. The form block would have a shape similar to that of Figure 8.

The practical depth of the first draw for either the Guerin or hydroforming process is limited by the reduction of the diameter of the part. The diameter should not be reduced by more than 20 percent by any draw, no matter what forming process is used [32]. Due to this constraint, PED recommends using two progressive dies to form the wing since the final diameter of the outer bend is 64 percent of the original dimension.

Assuming the Guerin process is used and two steps are needed to form wing halves, production rates equivalent to half that of the blanking processes are obtainable per step. With a production rate of 3.75 wing halves per minute (half the blanking rate), the RC per step is estimated to be $0.32 per wing. Combining the costs for both forming steps, the total RC per wing is $0.64. Since the die cost for the Guerin process is very low, this cost is assumed negligible. With production rates lowered, setup cost for the Guerin process, compared to the blanking process, will increase. Therefore, an annual setup cost (NRC) four times that of $907.C4 (previously calculated) is expected. This cost is equivalent to a NRC of $0.04 per wing. Total estimated forming cost per wing using the Guerin process is $0.68.

The implementation of the Guerin process for wing forming and shaping has the potential to lower total production cost by 28.9 percent, or a savings of $5.91 per wing.

4. Spot Welding

Current spot welding procedures for the AATAC Flex-Wing are quite detailed and costly. Fixturing is a cost problem, but can be addressed by developing more elaborate holding devices. A fixture, similar to that of Figure 5, could be attached to a press brake and used to decompress both wing

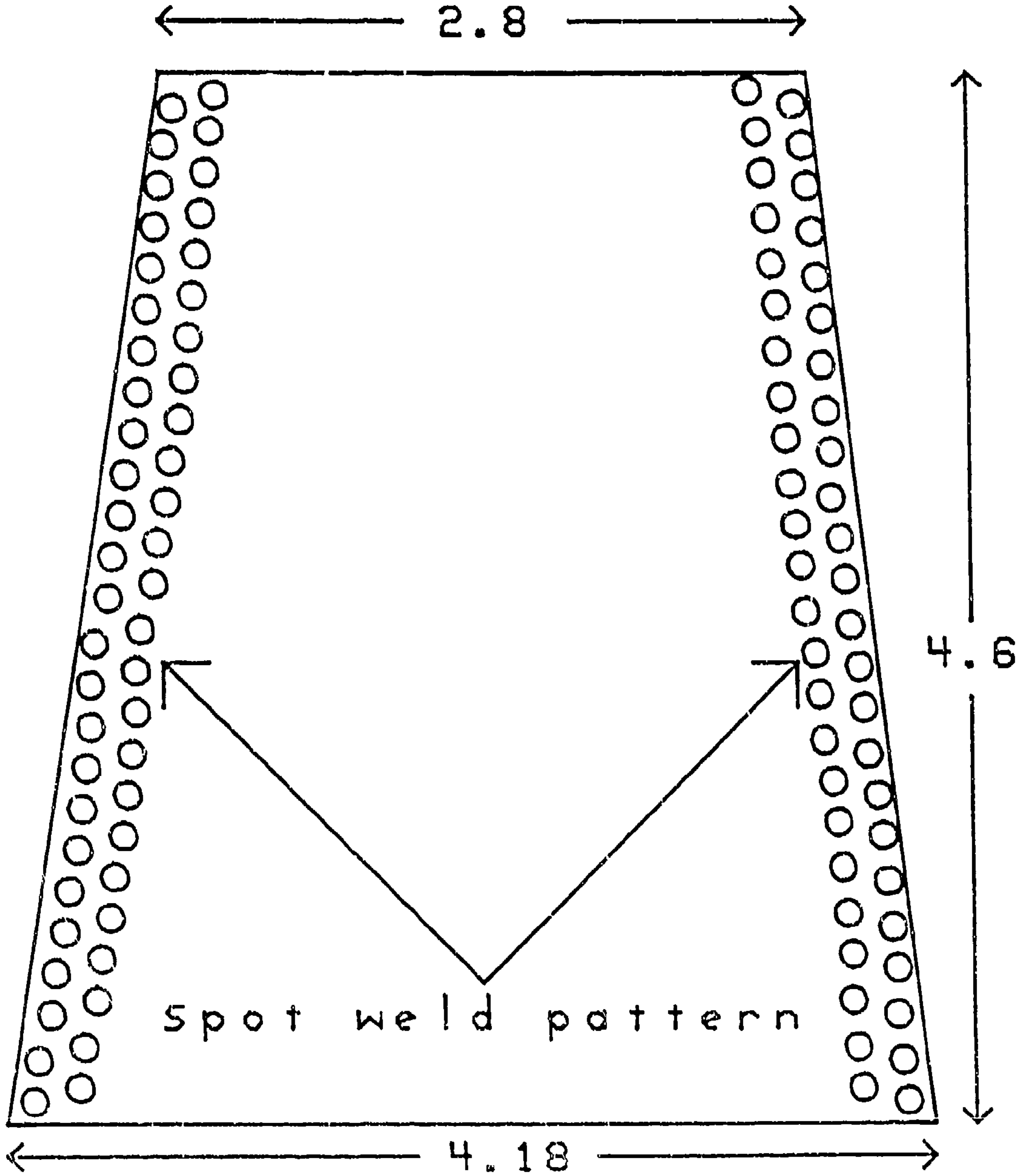


Figure 5. Fixture clamp and spot weld pattern - not to scale.

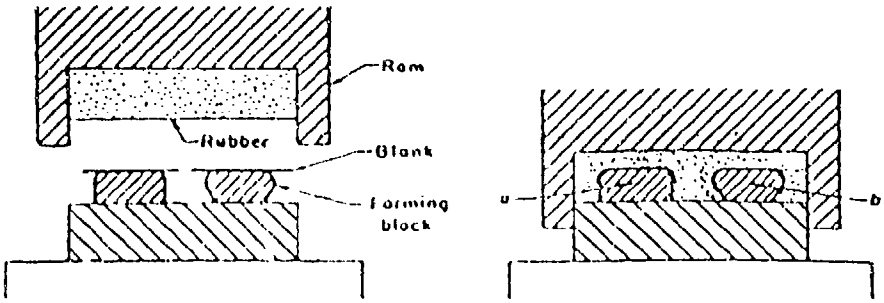


Figure 6. Guerin process for forming sheet metal [31].

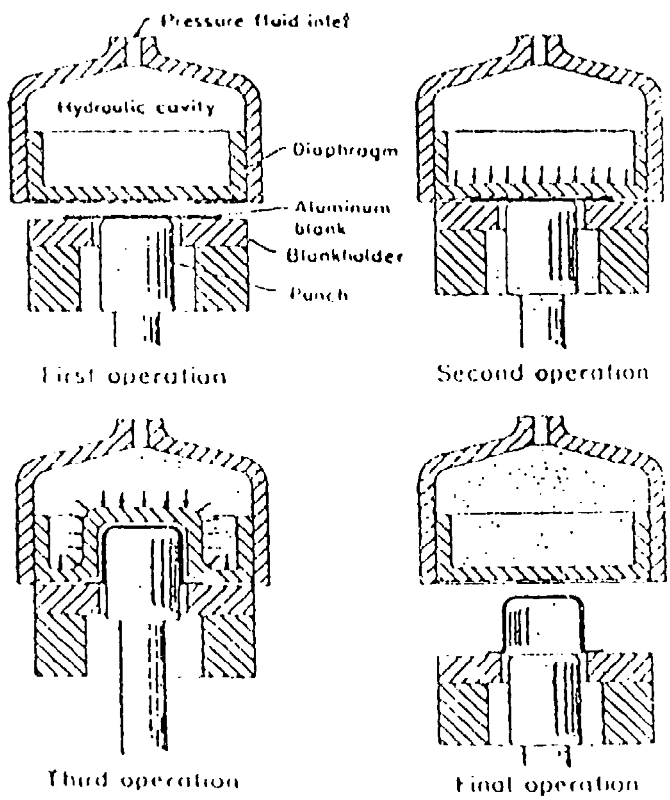


Figure 7. Hydroform process showing (1) blank in place, no pressure in cavity, (2) press closed and cavity pressurized, (3) ram advanced with cavity maintaining fluid pressure, and (4) pressure released and ram retracted [31].

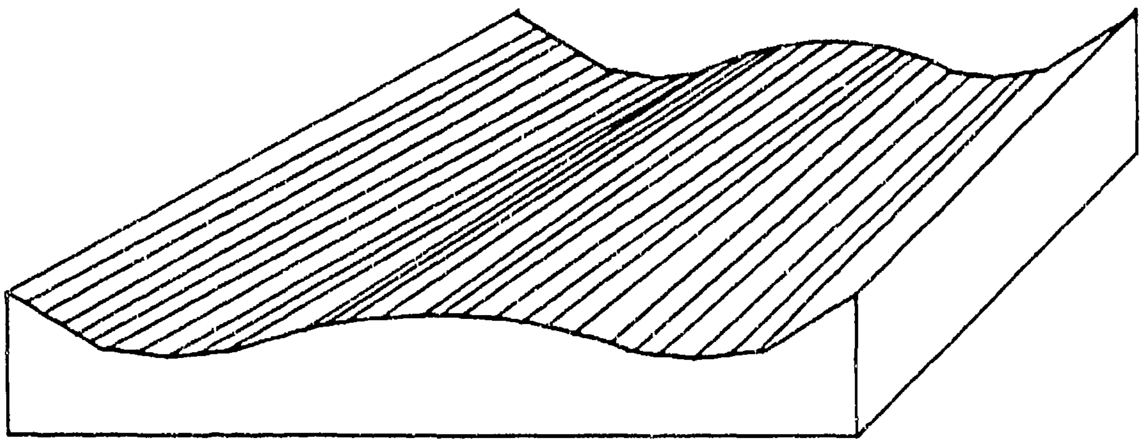


Figure 8. AATAC form block used in hydroforming and Guerin processes.

halves while spot welding is performed, thus decreasing handling and clamping time and lowering overall fixturing costs. Another costly issue is the spot welding time. With high production numbers, such as 96,000 flex-wings annually, the introduction of a more automated process is needed. A robotic spot welder could significantly increase production rates and at the same time dramatically lower touch labor costs. An example of a spot welder with programmable robotic capabilities is the Series 1 with an IAPX88/10 controller developed by Automated Process, Inc. (API). The Series I is capable of spot welding four corners of a 9-in. x 3-in. box in 1.9 seconds; the controller has four bytes of memory to program spot welding sequences. The Series 1 also has horizontal and vertical resolutions of 0.00055 and 0.00048 inches, respectively; therefore, detailed requirements may be met [33].

In general, spot welding is very fast. The actual time per nugget, or weld, is approximately 1/20th of a second. Therefore, if the nugget or weld locations are close together and a programmed robot is performing the spot welding, twenty spots potentially may be welded.

Assuming a robotic welder similar to the Series 1 with controller is used in the spot welding process, along with fixture modifications, the expected welding costs are as follows:

Wing Halves. The Series 1 with controller cost $80,000. Assume that this investment is necessary and that two purchases are needed during the 10.5 year production. The NRC per wing for this purchase is $0.16. A fixture like Figure 5 costs $3,000 annually [34]. The setup and handling costs are assumed to be 15 percent of the annual NRC. Therefore, the total annual NRC is $19,975 (0.21 per wing). With an expected production rate of 20 welds per second, the 114 welds (doublers not included) necessary to join the wing halves together costs $0.06 per wing, the total RC. The total spot welding costs (doublers not included), is $0.27 per wing. This method lowers the wing half spot welding costs by 94 percent, the overall cost by 20.8 percent and results in a savings of $4.27 per wing.

Doublers. Handling time in this process is the same as previously calculated in Section III. It is expected that 0.47 minutes is needed to position and secure doublers for spot welding. This RC is $0.27 per wing half. A total of 57 welds are necessary for joining the doubler to the wing half; costs, using the Series 1, are $0.03 per wing half. Total RC per wing half is $0.30. The NRC is made-up of the setup time. It is expected that 0.3 hours is needed for daily setup over a 207-day production life. A total of 62.1 hours is needed for annual setup, or a NRC of $0.01 per wing half. Total doubler spot welding costs per wing is $0.62. This estimate reduces the doubler spot welding cost by 88.5 percent, the overall cost by 23.5 percent and results in a savings of $4.80 per wing.

C. Manufacturing Considerations Summary

It was determined that two major cost drivers, spot welding and shaping of wing halves, exist in the current method of production. By concurrent blanking of the doubler and wing half and incorporation of the recommended die, a total savings in the blanking process of 32 percent is expected. Further savings will be realized with the use of the new die, shown in Figure 4, since the trimming process is incorporated into the blanking process.

Through implementation of the Guerin process for wing shaping and forming, a cost reduction of 28.9 percent is estimated. Welding automation offers a potential 88.5 percent cost reduction in the welding operation and overall cost reduction of 23.5 percent

In conclusion, the manufacturing process changes proposed in this report would result in an overall savings of $15.00 per wing. A production of 96,000 wings per year will realize a total annual savings of $1,440,000. See Table 5 for cost analysis summary of recommended production changes.

VI. MATERIALS IMPACT

At the request of the Structures Directorate, PED, along with key inputs from JPL and Machine Craft, assessed the impact of using different materials for the AATAC Flex-Wing on production methods and costs.

A. Methodology

Several material characteristics were considered for a replacement material candidate for the AATAC Flex-Wing. The current flex-wing material, stainless steel 17-7 PH, set the standard for all characteristics considered. Parameters equal to or better than to those of 17-7 PH were desired. Aluminum, copper, steel, nickel and a host of several other material alloy types were initially included in PED's analysis. However, tensile and yield strength, stress corrosion, spot weldability and cost, limited the selection to titanium, copper, stainless steel and nickel alloys. To obtain a working list of material, PED referenced tensile and yield strengths, first. Some 40 or 50 candidates surfaced. The list was eventually reduced to seventeen, based on workability and machinability of each material candidate. Table 6 is a listing of potential replacement candidates, along with representative characteristics of each. The recommendation of Inconel 718 and Stainless Steel A286, by Machine Craft, influenced PED to include these alloys.

B. Material Analysis

Once a workable material list was obtained, PED focused its attention on performance criteria and problem area of the current material. Stress corrosion was determined to be the main disadvantage in the performance of 17-7 PH, but elasticity and strength were significant advantages. Candidates were analyzed based on the following: (1) criticality, (2) material form, (3) elasticity (4) stress corrosion, (5) weldability, and (6) costs.

1. Criticality and Material Form

All alloys that made the second cut had several characteristics comparable, if not better, to that of 17-7 PH. However, some of these alloys were not obtainable in specified material form; and some were of a critical nature. Table 7 is a list of those materials eliminated, based on these parameters.

TABLE 5. Cost Analysis Summary for Recommended Production Changes - AATAC Wing.

Production Rate: 96,000/Yr
Material: 17-7 PH

Process	Recurring Cost/Part	Nonrecurring Cost Annually	Total Cost per Part	Total Cost per Wing	Percent Cost/Wing	Reduction (%) Change	Reduction (%) Overall Change
Purchase Material	$0.46	$0.00	$0.46	$0.92	17.85%	0.00%	0.00%
Mill Anneal	$0.01	$840.00	$0.01	$0.02	0.36%	0.00%	0.00%
Blank	$0.08	$8,907.04	$0.13	$0.25	4.91%	32.43%	0.59%
Fold Wing Tab	$0.04	$504.00	$0.04	$0.08	1.46%	0.00%	0.00%
Clean (for welding)	$0.01	$0.00	$0.01	$0.02	0.38%	0.00%	0.00%
Spot Weld Doublers	$0.30	$2,173.50	$0.31	$0.62	12.08%	88.56%	23.48%
Debur	$0.05	$472.08	$0.05	$0.10	2.00%	0.00%	0.00%
Shape Wing Halves	$0.32	$3,628.16	$0.34	$0.68	13.15%	89.68%	28.91%
Clean (for heat-treat)							
Vapor Degrease	$0.03	$0.00	$0.03	$0.05	0.97%	0.00%	0.00%
Alkaline Clean	$0.01	$0.00	$0.01	$0.02	0.39%	0.00%	0.00%
Heat Treating	$0.83	$1,750.00	$0.83	$1.67	32.39%	0.00%	0.00%
Flatten Cusp	$0.22	$1,680.00	$0.23	$0.46	8.88%	0.00%	0.00%
Spot Weld Wing Halves	$0.03	$19,975.00	$0.13	$0.27	5.20%	94.05%	20.89%
Trimming	$0.00	$0.00	$0.00	$0.00	0.00%	100.00%	0.93%
TOTALS	$2.37	$39,929.78	$2.58	$5.15	100.00%	404.73%	74.80%

TABLE 6. Material Considerations for the AATAC Flex-Wing.

Record#	MATERIAL	CONDITION	TEMPER_F	MATL_FORM	COMPOSIT
1	SS420	N/A	400.00	BAR	0.15%-C, 1.00%-Mn, 1.00%-Si, 14.0%-Cr
2	SS440A	N/A	600.00	BAR	0.75%-C, 1.00%-Mn, 1.00%-Si, 18.0%-Cr
3	SS440B	N/A	600.00	BAR	0.95%-C, 1.00%-Mn, 1.00%-Si, 18.0%-Cr
4	SS440C	N/A	600.00	BAR	1.20%-C, 1.00%-Mn, 1.00-Si, 18.0%-Cr
5	SSPH13-8MO	H950	0.00	N/A	13.25%-Cr, 8.5%-Ni(b), 2.5%-Mo, 1.35%-Al
6	SSPH13-8MO	H1000	0.00	N/A	13.25%-Cr, 8.5%-Ni(b), 2.5%-Mo, 1.35%-Al
7	SS17-7PH	RH950	0.00	SHEET	18.0%-Cr, 7.75-Ni(b), 1.5%-Al
8	SS455	900	0.00	BAR	12.5%-Cr, 9.5%-Ni, 2.5%-Cu, 1.4%-Ti
9	SS455	H950	0.00	BAR	12.5%-Cr, 9.5%-Ni, 2.5%-Cu, 1.4%-Ti
10	SSPH15-7MO	RH950	0.00	SHEET	16.0%-Cr, 7.75%-Ni, 3.0%-Mo, 1.5%-Al
11	SSPH15-7MO	COLD ROLL	0.00	SHEET	16.0%-Cr, 7.75%-Ni, 3.0%-Mo, 1.5%-Al
12	CBC17200	N/A	0.00	SHEET	99.5%-Cu, 1.9%-Be, 0.20% Co
13	CBC17300	N/A	0.00	SHEET	99.5%-Cu, 1.9%-Be, 0.40%-Pb
14	CNC71700	N/A	0.00	SHEET	67.8%-Cu, 31.0%-Ni, 0.5%-Be
15	TIT-ALPHA-BETA	ANNEALED	320.00	SHEET	6%-AL, 4%-V, (Low O2)
16	INCONEL 718	N/A	0.00	SHEET	19.0%-Cr, 52.5%-Ni, 5.1%-Nb, 18.5%-Fe
17	SSA286	N/A	0.00	SHEET	15.0%-Cr, 26.0%-Ni, 55.2%-Fe

Record#	MATERIAL	TENSILE	YIELD	ELONGATION	ELASTICITY	CORROSION	SPOT_WELD	CUBIC_COST
1	SS420	250.00	215.00	8.00	29.00	Good	Excellent	0.77
2	SS440A	250.00	240.00	5.00	29.00	Fair	Good	0.80
3	SS440B	280.00	270.00	3.00	29.00	Fair	Good	0.80
4	SS440C	285.00	275.00	2.00	29.00	Fair	Good	0.80
5	SSPH13-8MO	200.00	205.00	6.00	29.40	Good	Excellent	0.00
6	SSPH13-8MO	200.00	190.00	6.00	29.40	Good	Excellent	0.00
7	SS17-7PH	210.00	190.00	3.00	29.58	Fair	Excellent	1.11
8	SS455	235.00	220.00	8.00	28.43	Fair	Excellent	0.00
9	SS455	220.00	205.00	10.00	28.43	Fair	Excellent	0.00
10	SSPH15-7MO	225.30	200.00	3.00	28.30	Good	Excellent	1.29
11	SSPH15-7MO	240.00	230.00	1.00	28.30	Good	Excellent	1.29
12	CBC17200	212.00	195.00	1.00	21.00	Excellent	Excellent	0.84
13	CBC17300	200.00	182.00	3.00	21.20	Excellent	Excellent	0.84
14	CNC71700	200.00	180.00	4.00	22.00	Excellent	Excellent	1.61
15	TIT-ALPHA-BETA	220.00	205.00	14.00	27.00	Fair	Excellent	11.61
16	INCONEL 718	185.00	153.00	0.00	29.00	Excellent	Excellent	4.82
17	SSA286	208.00	193.40	0.00	28.30	Fair	Excellent	2.69

TABLE 7. Critical Material and Undesirable Material Forms.

Material	Reason for Elimination
Stainless Steel 455	exotic, critical
Stainless Steel PH13-8MO	not made in required thickness
Stainless Steel 420	material form, bar only
Stainless Steel 440A	material form, bar only
Stainless Steel 440B	material form, bar only
Stainless Steel 440C	material form, bar only
Titanium-Alpha-Beta	critical

Note: Copper Nickel C71700 was also forced to be eliminated because it did not meet present manufacturing requirements. Copper Nickel can only be cold worked. After extensive research, PED came to the conclusion that a manufacturing design or procedure change, to accommodate cold working copper nickel, would not be feasible.

2. Elasticity

PED asked JPL to address the issue of a material substitute for the AATAC Flex-Wing. Bob Bamford, JPL scientist, suggested that we consider, as a criteria, the ratio of a materials strength to its modulus of elasticity. "Elasticity is the ability of a solid to deform in direct proportion to and in phase with increases or decreases in applied force without any permanent strain remaining upon complete release of stress" [35]. PED included this suggestion in its analysis and concluded that 17-7 PH yielded the better results and, in general, all stainless steels were exceptional. The copper alloys had the least desirable traits for this ratio. The nickel based alloy, Inconel 718, has an extremely good ratio, but its yield strength could pose a problem. Table 8 lists the ratios of each material.

3. Stress Corrosion

As mentioned, stress corrosion in 17-7 PH is a performance drawback. "Low alloy steels become increasingly susceptible to stress corrosion cracking or delayed failure as the strength level increases" [36]. The results of the PED material analysis yielded PH15-7MO as the most resistant candidate of the stainless steels. But the nickel and copper alloys are the leading substitutes when stress corrosion is considered. As mentioned in the first year report, "increasing the nickel content is beneficial" in lowering stress corrosion, this is an advantage of Inconel 718. However, copper alloys appear to be very immune to stress corrosion, and "although stress corrosion cracking of copper alloys occur in what is often thought to be clean air, cracking will not take place in the absence of a corrosive environment," a very desirable trait of copper beryllium [37].

TABLE 8. AATAC Wing Tensile to Elasticity Ratio.

Material	Tensile Strength-KSI	Modulus of Elasticity-KSI	Tensile/Elasticity Ratio
SS420	250	29	8.62
SS440A	250	29	8.62
SS440B	280	29	9.66
SS440C	285	29	9.83
SSPH13-3MO	200	29.4	6.80
SS17-7PH	210	29.58	7.10
SS455	235	28.43	8.27
SS455	220	28.43	7.74
SSPH15-7MO	225	28.3	7.95
SSPH15-7MO	240	28.3	8.48
CBC17200	212	21.2	10.00
CBC17300	200	21.2	9.43
CBC71700	200	22	9.09
-ALPHA-BETA	220	27	8.15
INCONEL 718	185	29	6.38
SSA286	208	28.3	7.35

4. Spot Weldability and Cost

The spot weldability of each material considered was excellent. Therefore, no welding advantages or disadvantages exists among the potential material replacements, when compared to 17-7 PH. But, since the spot welding is a critical step in the fabrication process of the wing, the introduction of a new material should not create any additional problems in the joining process.

Once production numbers of 96,000 wings annually are realized, material costs may drive overall production costs. Therefore, raw material costs is a potential concerning issue in the high rate production process of the AATAC Flex-Wing. PED referenced several material sources in the quest for realistic prices for each substitute candidate. Prices obtained were for sheet formed material and were given in dollars per pound. Because the density varied among each material considered, PED converted the prices to dollars per volume (cubic inches). All prices include a 42.5 percent markup for private industry considerations. Copper beryllium was $0.27 (per cubic inch) cheaper than the nearest stainless steel and $4 cheaper than the nickel alloy.

5. Material Substitute

PED performed a material analysis using in-house algorithms. Table 9 is the results of that evaluation. In the analysis each material candidate was rated based on its attributes compared to the best or most desired reference traits. Each parameter analyzed was assigned a multiplier, which represents its rank of importance to the performance of the material candidates as seen by PED. For instance, PED felt that elasticity was twice as important as spot weldability, therefore, elasticity has a multiplier of 2 as compared to 1 for spot welding. These multipliers are not presented here as being scientifically correct or accurate, but represent certain tradeoffs that must be considered in producibility analysis. Table 6 incorporates PED's assumptions. An accumulative total of each material's rating was tabulated. Evaluation of the scores indicates that PH15-7MO had over all higher ratings; however, stress corrosion would not be significally improved with this choice. Therefore, PED recommends copper beryllium C17200 or C17300. The decision is based on the copper alloys excellent stress corrosion and price ratings. Although elasticity in copper is about 25 percent lower than that of the stainless steels, PED feels this could be a possible tradeoff for increasing stress corrosion resistance.

One final note: PED's source for copper beryllium information is "Brush Wellman, Inc. (Cleveland), the free world's only beryllium producer" [37]. All of the beryllium processed by Brush Wellman is supplied from a Brush Wellman mine in Utah. Also, PED researched the hazards of beryllium dust particles. These particles appear to be troublesome only in a pure state. Since beryllium makes up just 2 percent of the copper alloy's composition, the hazards are nonexistant. If the beryllium was in a pure state, hazards of inhaling the dust created by grinding processes could be lowered by introducing moisture in the air and by wearing protective breathing devices.

TABLE 9. AATAC Wing Material Substitute Analysis.

	Tensile KSI X 1	Yield KSI X 1	Elasticity KSI X 2	Corrosion X 3.5	Spot Weld X 1	Cost X 1.5	Score
REFERENCE	225	200	29	Excellent	Excellent	$0.84	85.0
SSPH15-7MO/RH950	* 10 225	* 6.8 185	* 9.2 28.3	* 7.5 Good	* 10 Excellent	* 8.4 $1.29	* 74.1
SSPH15-7MO/COLD ROLL	* 10 240	* 10 230	* 9.2 28.3	* 7 .5 Good	* 10 Excellent	* 8.4 $1.29	* 77.3
CBC17200	* 7.2 212	* 8.8 195	* 5.2 23	* 10 Excellent	* 10 Excellent	* 10 $0.84	* 76.4
CBC17300	* 4.8 200	* 6.4 182	* 3.6 21	* 10 Excellent	* 10 Excellent	* 10 $0.84	* 68.4
INCONEL 718	* 4 195	* 0.8 155	* 10 29	* 10 Excellent	* 10 Excellent	* 1 $4.82	* 61.3
SSA286	* 6.4 208	* 8.4 193	* 9.2 28.3	* 5 Fair	* 10 Excellent	* 2.8 $2.69	* 54.9
CNC71700	* 4.8 200	* 6 180	* 4.4 22	* 10 Excellent	* 10 Excellent	* 7.2 $1.61	* 65.4
SS17-7PH	* 6.8 210	* 8 190	* 10 29.58	* 5 Fair	* 10 Excellent	* 9.2 $1.11	* 66.1

6. Summary

Copper beryllium C17200 is PED's material of choice to replace stainless steel 17-7 PH in the manufacturing of the AATAC Flex-Wing. Copper beryllium's low cost, ability to conform to the present manufacturing process (verbatim), high strength, and, most importantly, excellent stress corrosion resistance definitely makes it a potential replacement alloy.

VII. CONCLUSIONS/RECOMMENDATIONS

PED recommends:

A. The wing half mate of the wing tab should be redesigned because current prototypes are not meeting the present design tolerances and overall requirements.

B. The outlined automated procedures, discussed in this report, should be implemented in the flex-wing manufacturing process so that the maximum production cost savings may be realized.

C. Copper beryllium should be considered as a material replacement for 17-7 PH because of copper beryllium's strength, cost and stress-corrosion resistance.

D. The shelf life of the current and potential replacement materials be addressed more extensively to unlock the significance of this area.

E. Consideration be given to modifying the current flex-wing storage method to reduce stress corrosion cracking. It could be possible to modify storage containers to allow wings to be stored in an upright position and folded prior to use.

REFERENCES

1. Oberg, Erik, Jones, Franklin D., and Horton, Holbrook L., Machinery's Handbook, Industrial Press, Inc., New York, NY, 1975, pp. 2136-2137.

2. ibid., pp. 2124-2125.

3. DeGarmo, E. Paul, P.E., Materials and Processes in Manufacturing, Macmillan Publishing Co., New York, 1979, p. 416.

4. Ostwald, Phillip F., American Machinist Manufacturing Cost Estimating Guide, McGraw-Hill Publications Co., New York, 1983, p. 108.

5. DeGarmo, E. Paul, P. E., Materials and Processes in Manufacturing, New York, 1979, p. 16

6. Ostwald, Phillip F., American Machinist Manufacturing Cost Estimating Guide, McGraw-Hill Pulbications C., New York, 1983, p. 337

7. Peckner, Donald, and Bernstein, I. M., Handbook of Stainless Steels, McGraw-Hill Book Company, New York, 1977, p. 35.3.

8. Ostwald, Phillip F., American Machinist Manufacturing Cost Estimating Guide, McGraw-Hill Publications Co., New York, 1983, p. 360.

9. Peckner, Donald, and Bernstein, I. M., Handbook on Stainless Steels, McGraw-Hill Book Company, New York, 1977, p. 35.3.

10. ibid., pp. 7.5-7.6.

11. ibid., pp. 7.5-7.6.

12. ibid., pp. 7.5-7.6.

13. Ostwald, Phillip F., American Machinist Manufacturing Cost Estimating Guide, McGraw-Hill Publications Co., New York, 1983, p. 315.

14. ibid., p. 166.

15. Amos, Richard, and Brewer, Harold, "Producibility Analysis of the AATAC Wing Design, FY 86," Production Engineering Division, System Engineering and Production Directorate, Redstone Arsenal, AL, Section 4.1.

16. Ostwald, Phillip F., American Machinist Manufacturing Cost Estimating Guide, McGraw-Hill Publications Co., New York, 1983, pp. 316-317.

17. ibid., pp. 101-102.

18. ibid., pp. 109-110.

19. ibid., p. 361.

20. ibid., pp. 308-310.

REFERENCES (Cont'd)

21. ibid., pp. 338-339.

22. ibid., pp. 109-110.

23. ibid., pp. 316-317.

24. ibid., pp. 309-310.

25. ibid., pp. 308-310.

26. ibid., pp. 168-169.

27. Pirtle, D.A., "Stress Analysis for AATAC Flex Wing," Letter Report RD-ST-87-40, Structures Directorate, April 1987.

28. Manufacturing Cost Engineering Handbook, Edited by Eric M. Malstrom, Marcel Dekker, Inc., New York and Basel, 1984, p. 76.

29. DeGarmo, E. Paul, P.E, Materials and Processes in Manufacturing, Macmillan Publishing Co., New York, 1979, p. 436.

30. ibid., p. 437.

31. DeGarmo, E. Paul, P.E., Materials and Processes in Manufacturing, Macmillan Publishing Co, New York, 1979, pp. 436-437

32. Mil-Handbook-727, Design Guidance for Producibility, U.S. Department of Defense, Washington, DC, 1984, p. 4-71.

33. "Automated Processes, Inc., Publication," API's manufacturing brochure, 1322 Valley Run, Durham, NC, 1985.

34. Manufacturing Cost Engineering Handbook, Edited by Eric M. Malstrom, Marcel Dekker, Inc., New York and Basel, 1984, pp. 74-78.

35. ASM Metals Reference Book, American Society for Metals, New York and Basel, 1986, p. 26.

36. Greenfield, P., Stress Corrosion Failure, Mills and Boon Limited, London, 1971, p. 29.

37. ibid., p. 43.

38. Farnum, Gregory T., et al., "Quickread: Reclamation System Cuts Costs, Improves Finish," Manufacturing Engineer, September, 1987, p. 20.

BIBLIOGRAPHY

ASM Metals Reference Book. American Society for Metals, New York and Basel, 1986.

Amos, Richard, and Brewer, Harold, PED, SEPD, "Producibility Analysis of the AATAC Wing Design, FY 86," Section 4.1.

"Automated Processes, Inc., Publication," API"s manufacturing brochure, 1322 Valley Run, Durham, NC, 1985.

Degarmo, E. Paul, P.E., Materials and Processes in Manufacturing. Macmillan Publishing Co., New York, 1979.

Farnum, Gregory T., et al., "Quickread: Reclamation System Cuts Costs, Improves Finish," Manufacturing Engineer, September 1987.

Greenfield, P. Stress Corrosion Failure. Mills and Boon Limited, London, 1971.

Malstrom, Eric M., editor, Manufacturing Cost Engineering Handbook. Marcel Dekker, Inc., New York and Basel, 1984.

Metals Handbook. American Society for Metals, Metals Park, OH, 1985.

Mil-Handbook-727, Design Guidance for Producibility. U.S. Department of Defense, Washington, D.C., 1984.

Oberg, Erik, Jones, Franklin D. and Horton, Holbrook L. Machinery's Handbook, Industrial Press Inc., New York, NY, 1975.

Ostwald, Phillip F., American Machinist Manufacturing Cost Estimating Guide, McGraw-Hill Publications Co., New York, 1983.

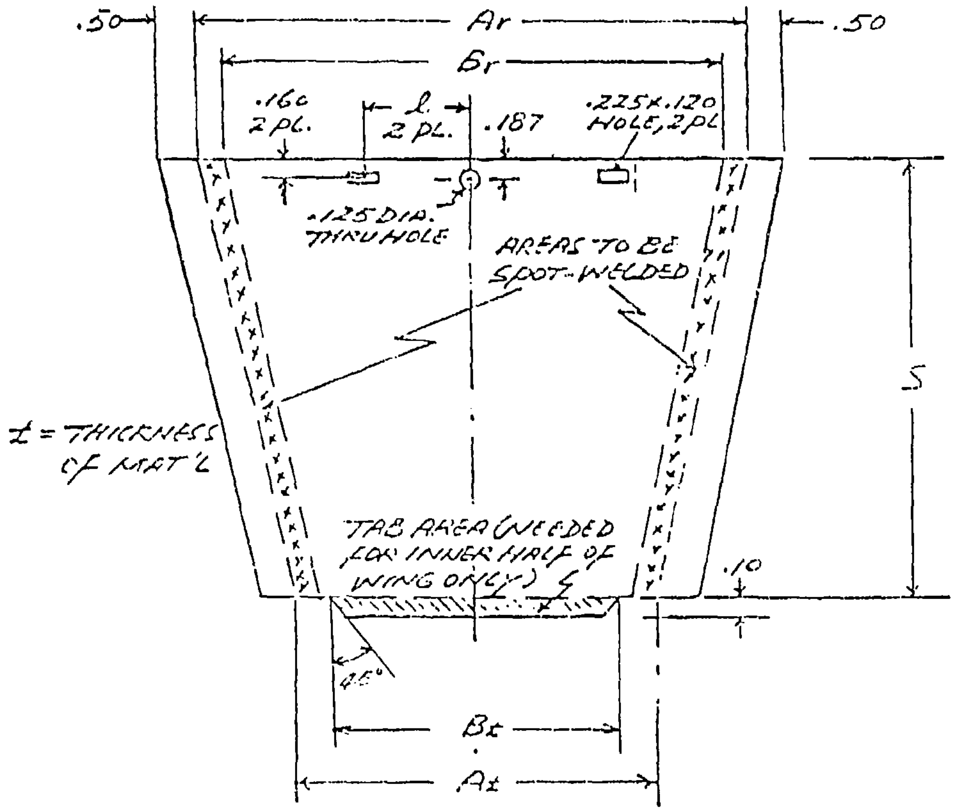
Peckner, Donald and Bernstein, I. M., Handbook of Stainless Steels, McGraw-Hill Book Company, New York, 1977.

APPENDIX A

DIMENSIONAL DRAWINGS

(PREPARED BY)	(DATE) 2/17/86	(REPORT NO.)
(CHECKED BY)	(DATE)	(PROJECT)

TITLE

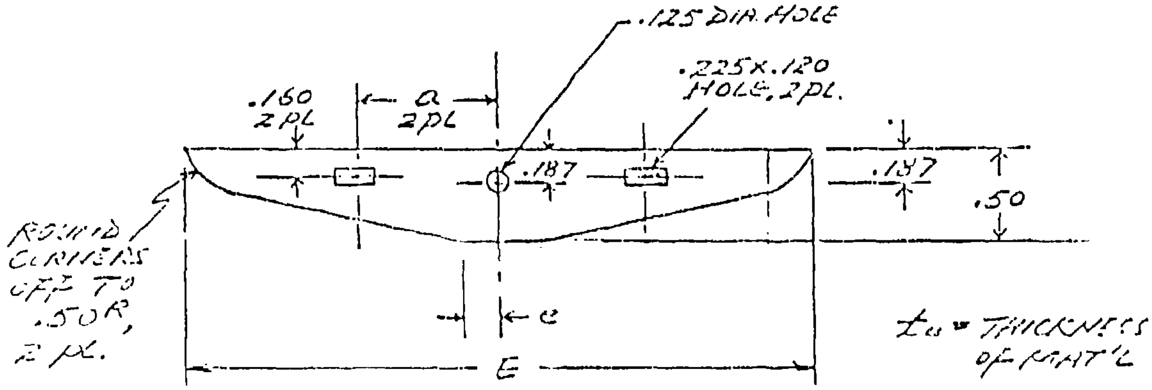


Design	t	S	A_r	B_r	A_t	B_t	ℓ
A1	.012	4.60	4.139	3.877	2.773	2.213	.910
A3	.012	4.60	4.174	3.932	2.773	2.213	.911

Figure A-1. Blank dimensions of wing halves.

(PREPARED BY)	(DATE)	(REPORT NO.)
	2/17/85	
(CHECKED BY)	(DATE)	(PROJECT)

TITLE



Design	t_u	E	a	e	R_u^*
A1	.025	3.458	.910	.30	4.928
A3	.025	3.493	.911	.30	3.115

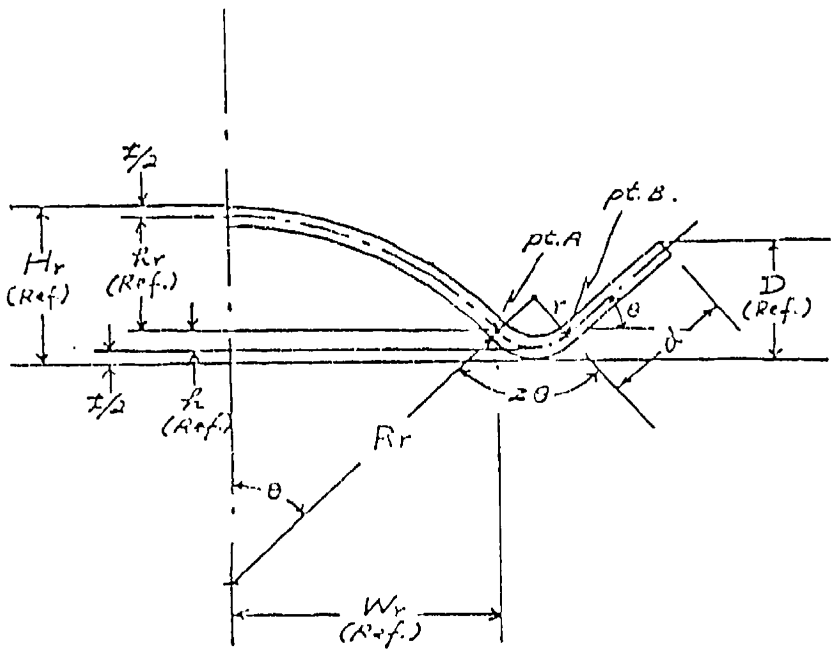
* R_u IS THE IN-PLANE RADIUS OF THE CURVED STRIP INTO WHICH THE DOUBLER WILL BE FORMED.

$$R_u = R_r + .5(t_r + t_u)$$

Figure A-2. Blank dimensions of doublers.

(PREPARED BY)	(DATE)	(REPORT NO.)
[signature]	2/17/82	
(CHECKED BY)	(DATE)	(PROJECT)

TITLE

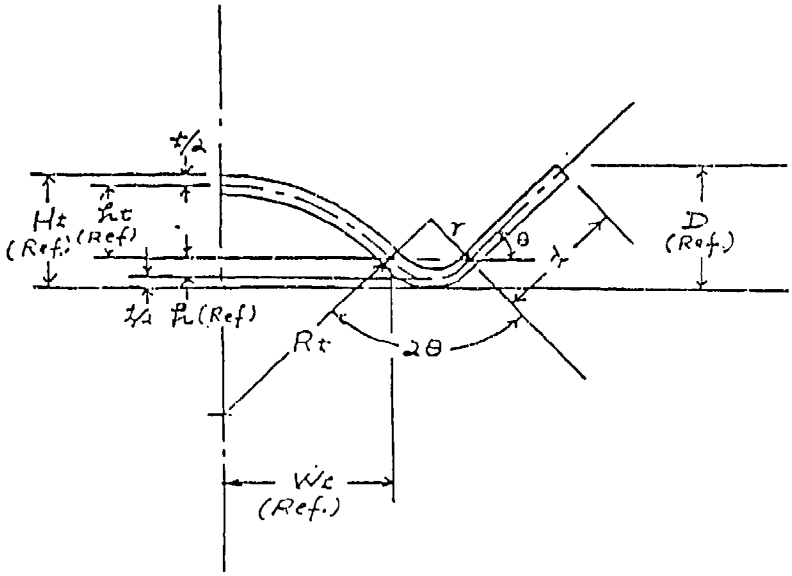


Design	R_r	r	θ	t	d	D	h_r	h	H_r	W_r
A1	4.929	.300	20.1°	.012	.63	.246	.300	.018	.330	1.694
A3	3.096	.300	30.5°	.012	.63	.371	.427	.041	.480	1.569

Figure A-3. Formed root-end section of wing halves.

(PREPARED BY)	(DATE) 2/17/81	(REPORT NO.)
(CHECKED BY)	(DATE)	(PROJECT)

TITLE

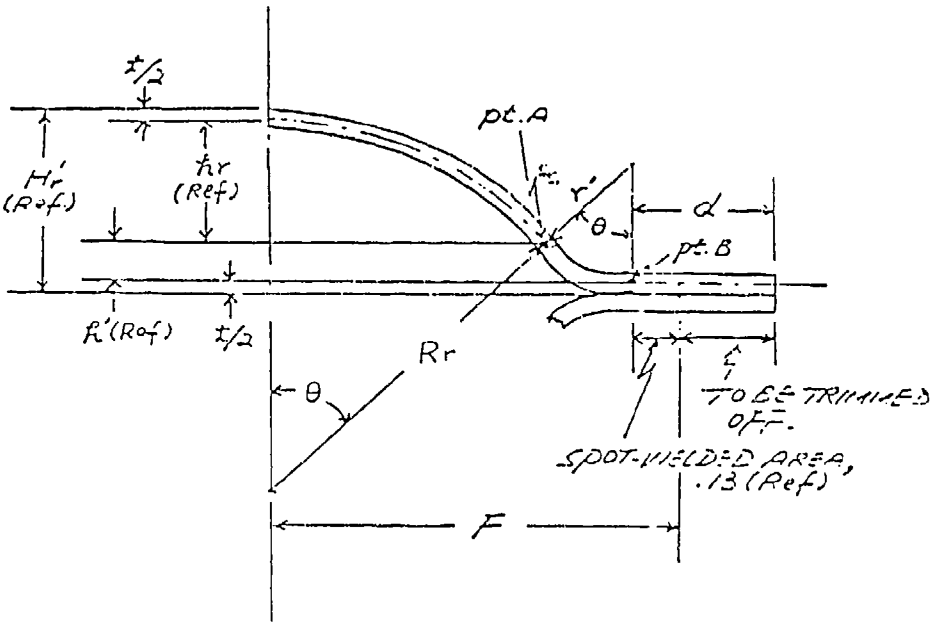


Design	Rt	r	θ	t	d	D	ht	h	Ht	Wt
A1	2.980	.30	20.1°	.012	.63	.246	.182	.018	.212	1.024
A3	1.764	.30	30.5°	.012	.63	.371	.240	.041	.293	.894

Figure A-4. Formed tip-end section of wing halves.

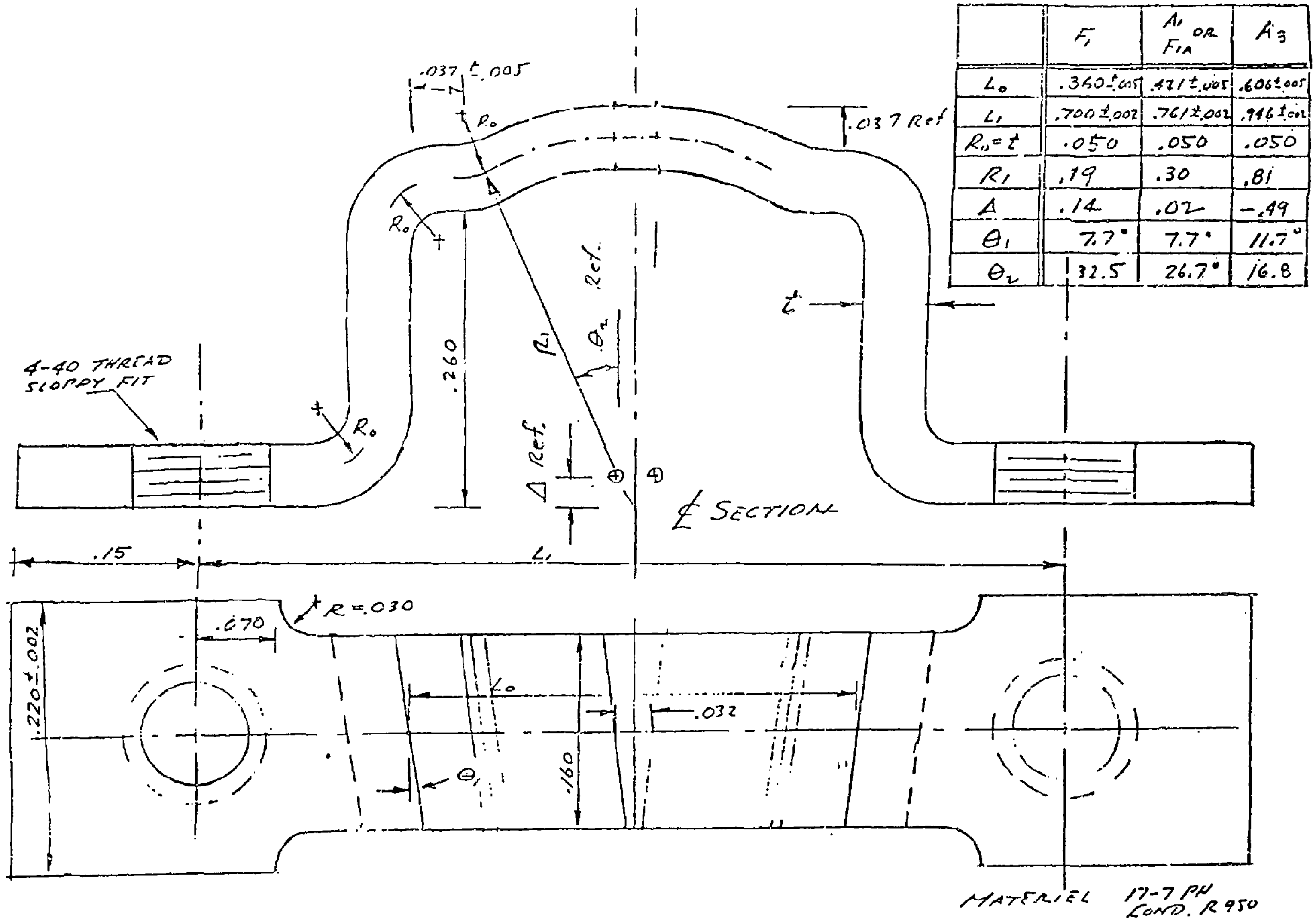
jpl

(PREPARED BY) | (DATE) 2/17/86 | (REPORT NO.)
HECKED BY) | (DATE) | (PROJECT)
TITLE



Design	R_r	r'	θ	t	d	h_r	h'	H_r'	F
A1	4.929	.60	20.1°	.012	.63	.300	.036	.349	2.04
A3	3.096	.60	30.5°	.012	.63	.427	.083	.522	2.01

Figure A-5. Wing section at root end.



	F_1	A_1 OR F_{1A}	A_3
L_o	.360 ± .005	.421 ± .005	.606 ± .005
L_1	.700 ± .002	.761 ± .002	.946 ± .002
$R_o = t$	.050	.050	.050
R_1	.19	.30	.81
A	.14	.02	-.49
θ_1	7.7°	7.7°	11.7°
θ_2	32.5	26.7°	16.8

Figure A-6. Attachment clip.

APPENDIX B

PROCESS CAPABILITY ANALYSES

PROCESS CAPABILITY ANALYSIS

DATE: 6 Aug 86

PROJECT: AATAC
PART NAME: WING BASE
PART NO: N/A
MATERIAL: 17-7 PH

	MIN HOLE DIA.	TOL.	SURF FINISH	MIN WALL THICK	RAW MATL COST	PROD COST	TOOL COST				SCORE	LDTIME WKS	APPLIC MATL
DESIGN REQUIREMENTS	0.112	0.002	125	0.05									
MACHINING	* 9	* 9	* 9	* 9	* 8	* 5	* 6	*	*	*	* 55	2	
FORGING	* 8	* 4	* 5	* 6	* 9	* 7	* 6	*	*	*	* 45	12	
EXTRUSION	*	*	*	*	*	*	*	*	*	*	* 0		
POWDER METALLURGY	* 7	* 7	* 8	* 7	* 7	* 7	* 7	*	*	*	* 30	10	
PERMANENT MOLD CASTING	* 4	* 4	* 6	* 6	* 8	* 7	* 6	*	*	*	* 43	12	
DIE CASTING	* 8	* 9	* 9	* 9	* 8	* 9	* 5	*	*	*	* 57	12	
INVESTMENT CASTING	* 8	* 8	* 9	* 9	* 7	* 7	* 8	*	*	*	* 56	12	
	*	*	*	*	*	*	*	*	*	*	* 0		
	*	*	*	*	*	*	*	*	*	*	* 0		
	*	*	*	*	*	*	*	*	*	*	* 0		

NOTES:

1. THREAD HOLES WITH ANY OPERATION

PROCESS CAPABILITY ANALYSIS

PROJECT: AATAC
PART NAME: WING BASE
PART NO: RD-ST-WF-304
MATERIAL: (1) 6061-T6 (2) 356-T6

DATE: 6 Aug 86

	MIN HOLE DIA.	TOL.	SURF FINISH	MIN WALL THICK	RAW MATL COST	PROD COST	TOOL COST					SCORE	LDTIME WKS	APPLIC MATL
DESIGN REQUIREMENTS	0.112	0.01	1.5	0.128										
MACHINING	9	9	9	9	8	5	6					55	2	1
FORGING												0		
EXTRUSION												0		
POWDER METALLURGY	7	7	8	9	7	7	7					52	10	1,2
PERMANENT MOLD CASTING	4	4	8	6	8	7	8					45	12	2
DIE CASTING	8	9	9	9	8	9	5					57	12	2
INVESTMENT CASTING	8	8	9	9	7	7	8					56	12	2
												0		
												0		
												0		

NOTES:

1. REAM AND C.SINK OPERATIONS N/A WITH INVESTMENT AND DIE CASTING

PROCESS CAPABILITY ANALYSIS

PROJECT: AATAC

DATE: 6 Aug 86

PART NAME: CENTER FUSELAGE

PART NO: RD-ST-WF-307

MATERIAL: (1) 6061-T6 (2) 357-T6

	MIN HOLE DIA.	TOL.	SURF FINISH	MIN WALL THICK	RAW MATL COST	PROD COST	TOOL COST				SCORE	LDTIME WKS	APPLIC MATL
DESIGN REQUIREMENTS	0.13	0.01	125	0.1									
MACHINING	9	9	9	7	8	2	6				50	2	1
FORGING											0	12	
EXTRUSION	2	8	9	7	6	6	7				47	10	1
POWDER METALLURGY											0	10	1,2
PERMANENT MOLD CASTING	4	5	8	8	9	8	6				48	12	2
DIE CASTING	9	9	9	9	8	9	3				56	12	2
INVESTMENT CASTING	9	9	9	9	7	7	6				56	12	2
CENTRIFUGAL CASTING	6	8	9	8	9	9	9				58	12	2
											0		
											0		

NOTES:

1. 3 DIFFERENT WALL THICKNESSES (.100 TO .125)
2. EXTRUSION REQUIRES THREE DIES AND MULTIPLE SET-UPS

APPENDIX C

COST ANALYSES WORKSHEETS

CENTRIFUGAL CASTING
COST ANALYSIS WORKSHEET

SYSTEM: AATAC

DATE: 20 AUG 86

PART: CENTER SECTION

ANALYST: R. AMOS

DRAWING NUMBER: RD-ST-WF-307

COST/PART: 50.808

PRODUCTION INFORMATION

BOX VOL.: 500
QUANTITY: 30000
LOT SIZE: 2500
MATERIAL: 356-T6

COST ANALYSIS

RECURRING COSTS

BASE CAST COST	30
DESIGN COMPLEXITY FACTOR	1.5
PROCESS COMPLEXITY FACTOR	1.2
LEARNING FACTOR	0.82
TEST AND EVALUATION COSTS	4.428
TOTAL RECURRING COSTS	48.708

NONRECURRING COSTS

BASE DIE/MOLD COST	35000
DESIGN COMPLEXITY FACTOR	1.5
TEST FIXTURE COST	10500
TOTAL NONRECURRING COSTS	63000

PART COST SUMMARY

RECURRING COST/PART	48.708
NONRECURRING COST/PART	2.1
TOTAL COST/PART	50.808

NOTES

1. DRILL AND REAM HOLES
2. TURN I.D. TO REMOVE IMPURITIES

System: AATAC
Part: Center Fuselage
Date: 28 Aug 86
Analyst: R. Amos

Production Units: 30000
Finshing Cost: 13.56754

****

Process: CNC Drilling
Material:Aluminum
Size: Cast Tube

Input Parameters	A	B	C	D
SFPM:	250	250	250	250
IPR:	0.003	0.003	0.003	0.003
Drill Diameter	0.18	0.13	0.132	0.138
Hole Depth	0.1	0.1	0.1	0.1
No. Holes	8	8	32	4
No. Operations	2	2	2	2
Fixture surface area	100	0	0	0
Tool Life	5000	5000	5000	5000
Recurring Cost=	1.470643	1.462131	5.849686	0.731746
Set Up Cost=	280	280	1120	140
Tooling Cost=	0.1	0.1	0.1	0.1
Fixture Cost=	50	0	0	0
Non-Recurring Cost (NRC)=	330.1	280.1	1120.1	140.1
Total Cost=	1.536663	1.518151	6.073906	0.739766
Drilling Cost=	9.868487			

****

Process: CNC Turning
Material:Aluminum
Size: Cast Tube

Input Parameters	A	B	C	D
SFPM:	1000	1	1	1
IPR:	0.037	1	1	1
Part Diameter:	5.8	0	0	0
Cut Length:	13.7	0	0	0
Cut Depth:	0.025	0	0	0
No. Cuts:	1	0	0	0
No. Operations:	3	0	0	0
Tool Width:	0.05	0	0	0
Fixture Area:	100	0	0	0
Tool Life:	5000	1	1	1
Position Cost=	0 [illegible]125	0	0	0
Machine Cost=	2.5[illegible]7004	0	0	0
Traverse Cost=	0.[illegible]4417	0	0	0
Deburring Cost=	0.7	0	0	0
Recurring Cost=	3.628922	0	0	0
Tooling Cost=	0.685	0	0	0
Set-Up Cost=	315	0	0	0
Fixture Cost=	50	0	0	0
Non-Recurring Cost=	365.685	0	0	0
Total Cost=	3.699059	0	0	0
Turning Cost=	3.699059			

DIE CASTING
COST ANALYSIS WORKSHEET

SYSTEM: AATAC — DATE: 3 SEP 86

PART: A-3 CLIP — ANALYST: R. AMOS

DRAWING NUMBER: N/A — COST/PART: 3.73552

PRODUCTION INFORMATION

BOX VOL.: 1
QUANTITY: 240000
LOT SIZE: 20000
MATERIAL: 17-7 PH
DIE LIFE: 40000

COST ANALYSIS

RECURRING COSTS

BASE CAST COST	1.9
DESIGN COMPLEXITY FACTOR	1.6
PROCESS COMPLEXITY FACTOR	1.35
LEARNING FACTOR	0.8
TEST AND EVALUATION COSTS	0.32832
TOTAL RECURRING COSTS	3.61152

NONRECURRING COSTS

BASE DIE/MOLD COST	3000
DESIGN COMPLEXITY FACTOR	1.6
TEST FIXTURE COST	960
TOTAL NONRECURRING COSTS	29760

PART COST SUMMARY

RECURRING COST/PART	3.61152
NONRECURRING COST/PART	0.124
TOTAL COST/PART	3.73552

NOTES

1. TAP HOLES 4-40

System: AATAC
Part: A-3 Clip
Date: 2? Aug 86
Analyst: R. Amos

Production Units: 240000
Finsaing Cost: 2.879832

****

Process: Semi-Automated Tapping
Material: 17-7 PH
Size: Bar

Input Parameters	A	B	C	D
SFPM:	50	1	1	1
IPR:	0.001	1	1	1
Diameter	0.118	0	0	0
Hole Depth	0.05	0	0	0
No. Holes	2	0	0	0
No. Operations	2	0	0	0
Fixture surface area	5	0	0	0
Tool Life	7500	1	1	1
Recurring Cost=	2.872192	0	0	0
Set Up Cost=	56	0	0	0
Tooling Cost=	0.05	0	0	0
Fixture Cost=	1.25	0	0	0
Non-Recurring Cost (NRC)=	57.3	0	0	0
Total Cost=	2.879832	0	0	0
Drilling Cost=	2.879832			

****

DIE CASTING
COST ANALYSIS WORKSHEET

SYSTEM: AATAC

PART: WING BASE

DRAWING NUMBER: RD-ST-WF-304

DATE: 14 AUG 86

ANALYST: R. AMOS

COST/PART: 2.781606

PRODUCTION INFORMATION

BOX VOL.: 3
QUANTITY: 120000
LOT SIZE: 2500
MATERIAL: 356-T6
DIE LIFE: 40000

COST ANALYSIS

RECURRING COSTS

BASE CAST COST	2
DESIGN COMPLEXITY FACTOR	1.1
PROCESS COMPLEXITY FACTOR	1.35
LEARNING FACTOR	0.82
TEST AND EVALUATION COSTS	0.24354
TOTAL RECURRING COSTS	2.67894

NONRECURRING COSTS

BASE DIE/MOLD COST	3500
DESIGN COMPLEXITY FACTOR	1.1
TEST FIXTURE COST	770
TOTAL NONRECURRING COSTS	12320

PART COST SUMMARY

RECURRING COST/PART	2.67894
NONRECURRING COST/PART	0.102666
TOTAL COST/PART	2.781606

System: AATAC
Part: Wing Base
Date: 14 Aug 86
Analyst: R. Amos

Production Units: 120000
Finshing Cost: 1.687180

****

Process: CNC End Milling
Material: Aluminum
Size: Plate

Input Parameters	A	B	C	D
SFPM:	1500	1	1	1
IPT:	0.01	1	1	1
TPR:	6	1	1	1
Tool Diameter:	0.2	0	0	0
Cut Length:	0.3	0	0	0
Cut Depth:	0.005	0	0	0
No. Cuts:	1	0	0	0
Tool Width:	0.15	0	0	0
Fixture Area:	. 10	0	0	0
Tool Life:	5000	1	1	1
No. Operations:	4	0	0	0
Position Cost=	0.2025	0	0	0
Machine Cost=	0.000152	0	0	0
Traverse Cost=	0.000012	0	0	0
Deburring Cost	0.7	0	0	0
Indexing Cost	0.7	0	0	0
Recurring Cost	1.602665	0	0	0
Tooling Cost	[illegible]	0	0	0
Set-Up Cost	4.3	0	0	0
Fixture Cost	2.5	0	0	0
Non-Recurring Cost	422.575	0	0	0
Total Cost	1.687180	0	0	0
Finishing Cost	1.687180			

Production Cost Analysis

System: AATAC
Part: Wing
Analyst: R. Amos
Date: 15 Sep 86

Production Rate: 120,000/Yr
Material: 17-7 PH

Process	Recurring Cost	Nonrecurring Cost	Cost/Piece	Cost/Wing
Purchase Material	.81	0	.81	1.62
Blank Shape (Wing)	.07	7984	.14	.28
Blank Shape (Doubler)	.07	1029	.08	.16
Form Contours	1.57	665	1.58	3.16
Fold Wing Tip Tab	1.16	665	1.17	1.17
Weld Doublers	.02	0	.02	.04
Heat Treat (RH 950)	.52	.03	.55	1.10
Flatten Cusps	1.33	665	1.34	2.68
Weld Wing Halves	.05	0	.05	.05
Trim Excess Material	.03	1650	.04	.04
Clean	.02	0	.02	.02
Total/Wing				10.32

APPENDIX D

TOW MISSILE WINGS

Wings

The TOW Missile uses 4 wings that fold into the center fuselage and are spring loaded to pop out after the missile has been launched. The wings then lock into place and are used to stabilize the missile, not steer it. All 4 wings are machined to the dimensions in Drawing 10190132. The wings can be made from the following materials:

(1) Plate, AL Alloy 2024-T351 per QQ-A-250/4 Temper 351

(2) Bar, AL Alloy 2024-T4 per QQ-A-225/6 Temper T4

(3) Bar, Al Alloy 2024-T3510 per QQ-A-200/3 Temper T3510

Although all 4 wings are machined identically, they are not all interchangeable. Wing No. 2 (10190130) and Wing No. 4 (10084378) have a toggle switch riveted to them per Drawing 10190131. These 2 wings must be in the correct position because each toggle switch operates at different timings. Wing No. 1 and Wing No. 3, however, are not connected to a toggle switch and only these 2 may be interchanged.

The wings are not machined by HAC, but are bought from a vendor in the finished form. The last buy from 7-86 is listed below:

	Price	Quantity
Wing Machined 10190132	7.13	48750
Wing No. 4 10084378	11.07	24380
Wing No. 2 10190130	11.07	24380

The wings are assembled to wing lugs which are welded to the Aft Flight Motor Case. The following parts are used in assembly:

Part Number	Part Description	Quantity
13218279	Case, Aft, Flight Motor	1
10190132	Wing Machined	2
10084378	Wing No. 4 Assy	1
10190130	Wing No. 2 Assy	1
10189293	Spring, Wing	4
10189289	Spring, Wing Lock	4
10084767	Pawl	4
10218304	Roll Pin, Slotted	4
115[illegible]0136	Pin, [illegible]ng	4

Center Structure

The wings, which are connected to the Aft Flight Motor Case, fold into the center structure through slots that have been punched into the walls. The center structure is magniformed to the Aft Flight Motor Case. The center structure is made of aluminum alloy impact 6061-T6 per MIL-A-12545 Temper T6. The following operations are involved in the machining of the center structure:

Cost Date on Center Structure

The center structure machined part number is 13218295. The structure is bought in the preformed condition (Part Number 11500082-461). The past 5 buys are listed below:

Date	Quantity	Unit Price
May 84	21,000	16.15
Sep 84	7,620	16.15
Aug 85	26,950	16.05
May 86	4,900	16.22
Jun 86	12,480	16.90

Operation Number	Operation Description
10	Issue
20	NC Lathe
30	Drill and Punch
40	Countersink
50	Punch
60	Vapor Degrease
70	Deburr (ECD)
80	Chem Coat
[illegible]	Store

20 Numerically Controlled (NC) Lathe

This operation requires one operator to run 3 NC Lathes. First, grooves are machined in the top outside wall of the structure to allow for the magniform process (Figures 2, 3, and 4). Next, a hole is machined in the center of the internal depression (See Figures 2, and 5). Last, a groove is machined in the bottom inside wall of the structure (Figure 6).

30 Drill and Punch

This operation also requires one operator to run 3 machines. First, the part is dipped in a Keenzol P and oil solution to wash out the chips and lubricate the part. Eight tear drops are formed in the internal depression by drilling 3 holes of different sizes (Figure 6). Then, 43 various holes are punched in the walls of the structure (Figure 7).

40 Countersink

This operation countersinks 22 of the 43 holes in the walls of the structure (Figure 8).

50 Punch

Every fifth part is dipped in a Keezol P and oil solution for lubrication. This operation punches 2 elliptical slots for the flight motor exhaust, 4 long slender slots for the wings, and 2 short slender slots (Figures 9, 10, and 11).

70 Electrochemical Deburring (ECD)

This operation is an ECD process. The following sequence is used:

(1) Part is loaded in a tank containing ECD electrolyte solution.

(2) Machine parameters are set at:

Amperage	350 $\pm$ 50 amps
Voltage	15 volts
Cycle Time	60 $\pm$ 5 seconds

(3) Run the cycle.

(4) Unload part and rinse with hot water (150 $\pm$ 25 °F) for 1-3 seconds.

(5) Place part in acid clean tank for 2-3 minutes.

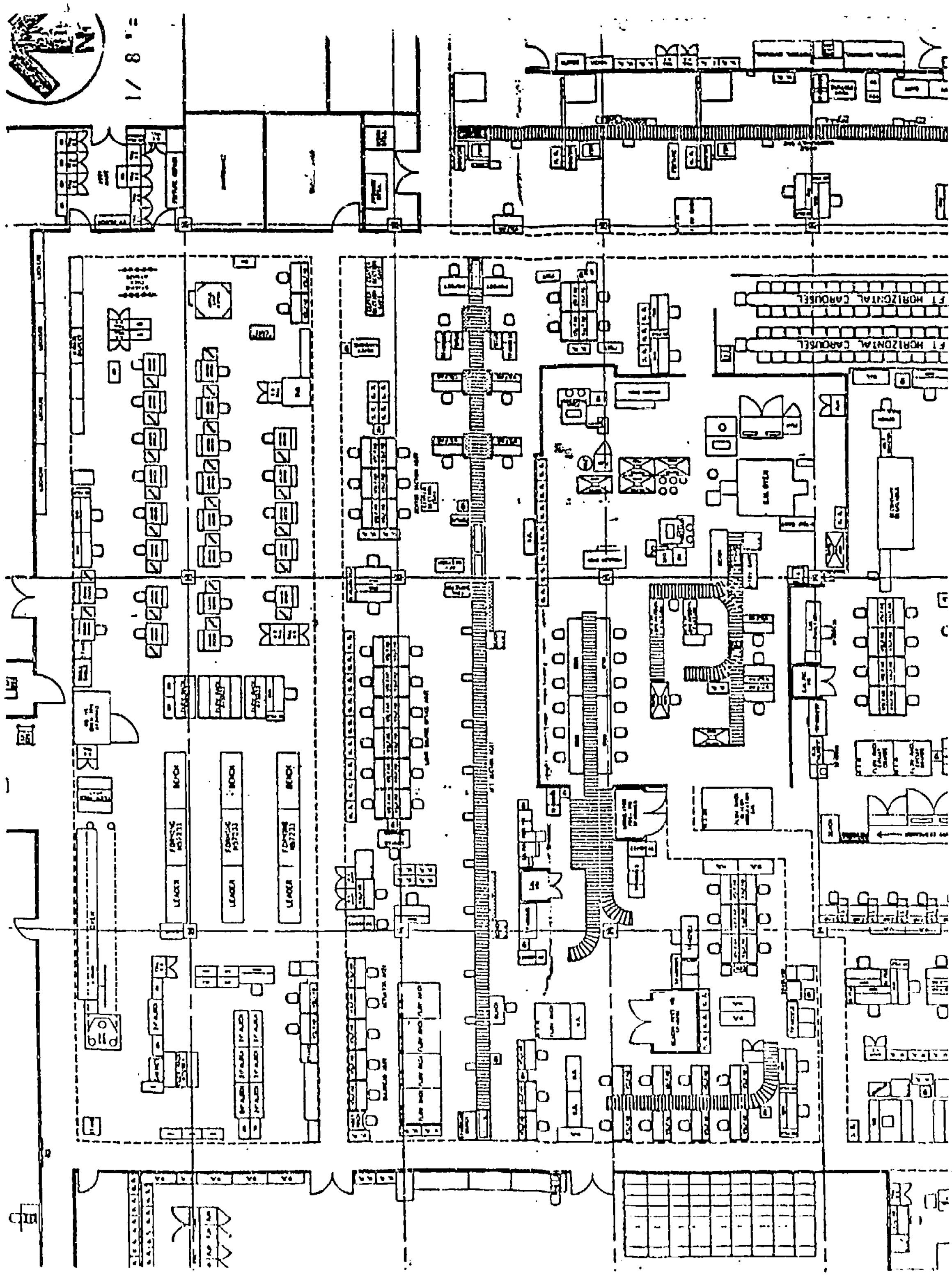
(6) Unload part and rinse with hot water (150 $\pm$ 25 °F) for 1-3 seconds.

(7) Drain, drip dry and package.

The ECD electrolyte tank is made-up of a solution of Sodium Nitrate and dionized water. The acid clean tank is made-up of Omega No. 521-5 acid (a product of Omega Chemical Co., Inc.) and tap water. Both tanks are monitored by Process Engineers and the solution is changed as necessary.

APPENDIX E

ASSEMBLY PLANT LAYOUT



APPENDIX F

FLEX-WING PRODUCIBILITY SUPPORT STUDY

Flex-Wing Producibility Support Study
27 April 1987

SEPD will provide the following for the flex-wing producibility study for FY 87:

(1) Estimate production costs of the flex-wing based on current method of fabrication for 24,000 sets of flex-wings per year and a total of 250,000 sets. (1 set = 4 flex-wings.)

(2) Review in detail the AATAC Flex-Wing structural drawing for possible ways to reduce production costs using the current fabrication methods. Consult with JPL and the T&M contractor to suggest ways of improving the current method of manufacturing.

(3) Inve gate different fl x-wing manufacturing methods, estimate costs, and compare methc for cost effectiveness and production repeatability.

(4) ssess the impact of using different materials for the flex-wing on product on methods and costs.

(5 Provide the Warhead and Fuze Function a technical report on the res t of e two-year producibility study by SEPD or the AATAC Flex-Wing and mi

(6) Provide the Warhead and Fuze Function an anticipated cost breakdown for ea of the listed tasks no later than 11 May 1987.

APPENDIX C

FLEX-WING MANUFACTURE AND ASSEMBLY PROCEDURE

APPLICATION		REVISIONS			
NEXT ASSY	USED ON	REV	DESCRIPTION	DATE	APPROVED
			Flexible Wing Manufacture and Assembly Procedure		

Material: 17-7 PH Stainless Steel - Condition C

1. Mill anneal sheets of material at 1950±25°F to reach condition A.

2. Machine and form to dimensions per figure 3 of drawing RD-ST-WF-337 for A3 wing or figure 3 of drawing RD-ST-WF-336 for A1 wing.

3. Fold tab at wing tip (only on lower wing half) to a minimum bend radius of 0.018 inches (150% skin thickness).

4. Clean parts in sonic cleaner with M50 solution for thirty (30) minutes.

5. Spot weld doublers to wing halves per pattern in figure 2 of drawing RD-ST-WF-337 for A3 wings or figure 2 of drawing RD-ST-WF-336 for A1 wings.

SEE NOTE

6. Deburr all parts.

7. Shape and form wing halves to figures 6 and 7 of drawings RD-ST-WF-337 for A3 wing or RD-ST-WF-336 for A1 wing.

8. Clean material by vapor degreasing and alkaline cleaning processes in a protective atmosphere or vacuum.

9. Heat treat wing halves using following methods. Because of the thinness of the wing halves, a mild steel support contoured to the same shape as the wing half should be used to prevent sagging of the material during heating. To avoid contamination, the supports should undergo the same cleaning procedures as the wing materials.

   a. Austenite conditioning
      Heat to 1750 ±15°F; hold for 10 minutes; air cool to condition A-1750.

   b. Martensite transformation
      Cool within one (1) hour to -100%F±10°F; hold for eight (8) hours to reach condition RH-100.

REV																									
SHEET																									
REV STATUS OF SHEETS	REV																								
	SHEET																								

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON FRACTIONS DECIMALS ANGLES ± ± ±			U.S. ARMY MISSILE COMMAND REDSTONE ARSENAL, ALABAMA	
MATERIAL	DATE			
	ENGINEER		FLEX WING PROCEDURE	
	CHECKED			
	PREPARED			
	SUBMITTED		SIZE A	FSCM NO. 18876	DRAWING NO. RD-ST-WF-339
	APPROVED BY ORDER OF COMMANDER USAMICOM		SCALE	SHEET 1/2

APPLICATION		REVISIONS			
NEXT ASSY	USED ON	REV	DESCRIPTION	DATE	APPROVED
			Flexible Wing Manufacture and Assembly Procedure		

c. Precipitation hardening
A1 wing - heat to 950±10°F; hold for one (1) hour and air cool to reach condition RH-950.
A3 wing - heat to 1050±10°F; hold for one (1) hour and air cool to reach condition RH-1050.

10. Wing assembly

a. Flatten the cusp area of the lower wing half (with tab) by flattening the central, gently curved section of the wing half and hold in a fixture.

b. Tuck upper wing half (without tab) under folded tab of the bottom wing half.

c. Flatten cusp of upper wing half.

d. Clamp chord lengths together and spot weld per figure 1 of drawing RD-ST-WF-337 for A3 wing or drawing RD-ST-WF-336 for A1 wing.

e. Trim the assembled wing to dimensions per figure 5 of drawing RD-ST-WF-337 for A3 wing or drawing RD-ST-WF-336 for A1 wing.

**NOTE:

Because of past problems, extra care is needed during the spot welding procedure of both the doubler assembly and the wing halves assembly.

The best results were achieved using a UNITEK 125 machine with the following wettings:

° polarity - low

° pulse - medium

° heat - approximately at 2:00 o'clock position

The RWMA Class 2 electrodes with the UNITEK 125 hand piece was used for wing spot welding. The electrode pressure was set at 10 pounds.

REV																										
SHEET																										
REV STATUS OF SHEETS	REV																									
	SHEET																									

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON FRACTIONS DECIMALS ANGLES ± ± ±	DATE	U.S. ARMY MISSILE COMMAND REDSTONE ARSENAL, ALABAMA
	ENGINEER	FLEX WING PROCEDURE
MATERIAL	CHECKED	
	PREPARED	
	SUBMITTED	SIZE A · FSCM NO. 18876 · DRAWING NO. RD-ST-WF-330
	APPROVED BY ORDER OF COMMANDER USAMICOM	SCALE · SHEET 2/2

NOTES:

1. MATERIAL STAINLESS STEEL 17-7 PH.
2. SEE PROCEDURE DRAWING RD-ST-WF-329.
3. ONLY ON THE LOWER WING HALVES.

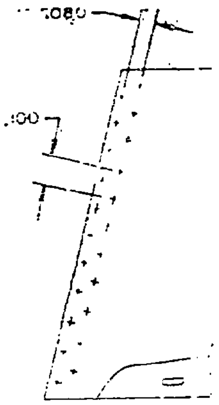
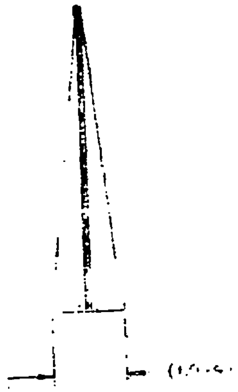


FIG 1 ... PATTERN

SCALE: NONE
SPOTWELD WHERE
INDICATED



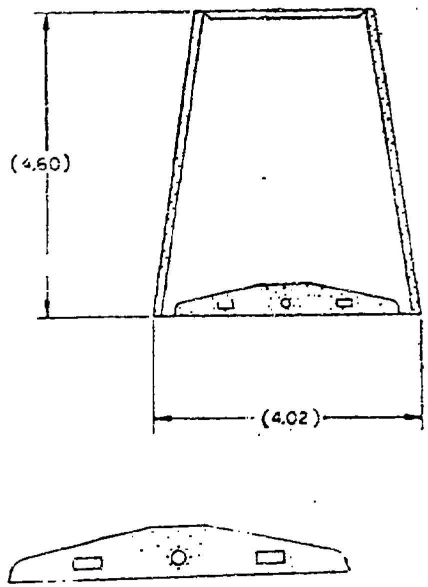


FIG 2 DOUBLER PATTERN

SCALE: NONE
SPOTWELD WHERE
INDICATED

U.S. ARMY MISSILE COMMAND
REDSTONE ARSENAL, ALABAMA

WING, FLEX (A3)

DATE 86-1-10

SIZE D | FSCM NO. 18876 | DRAWING NO. RD-ST-WF-337

SCALE NONE | SHEET 1 OF 2

NEXT ASSY | USED ON
APPLICATION

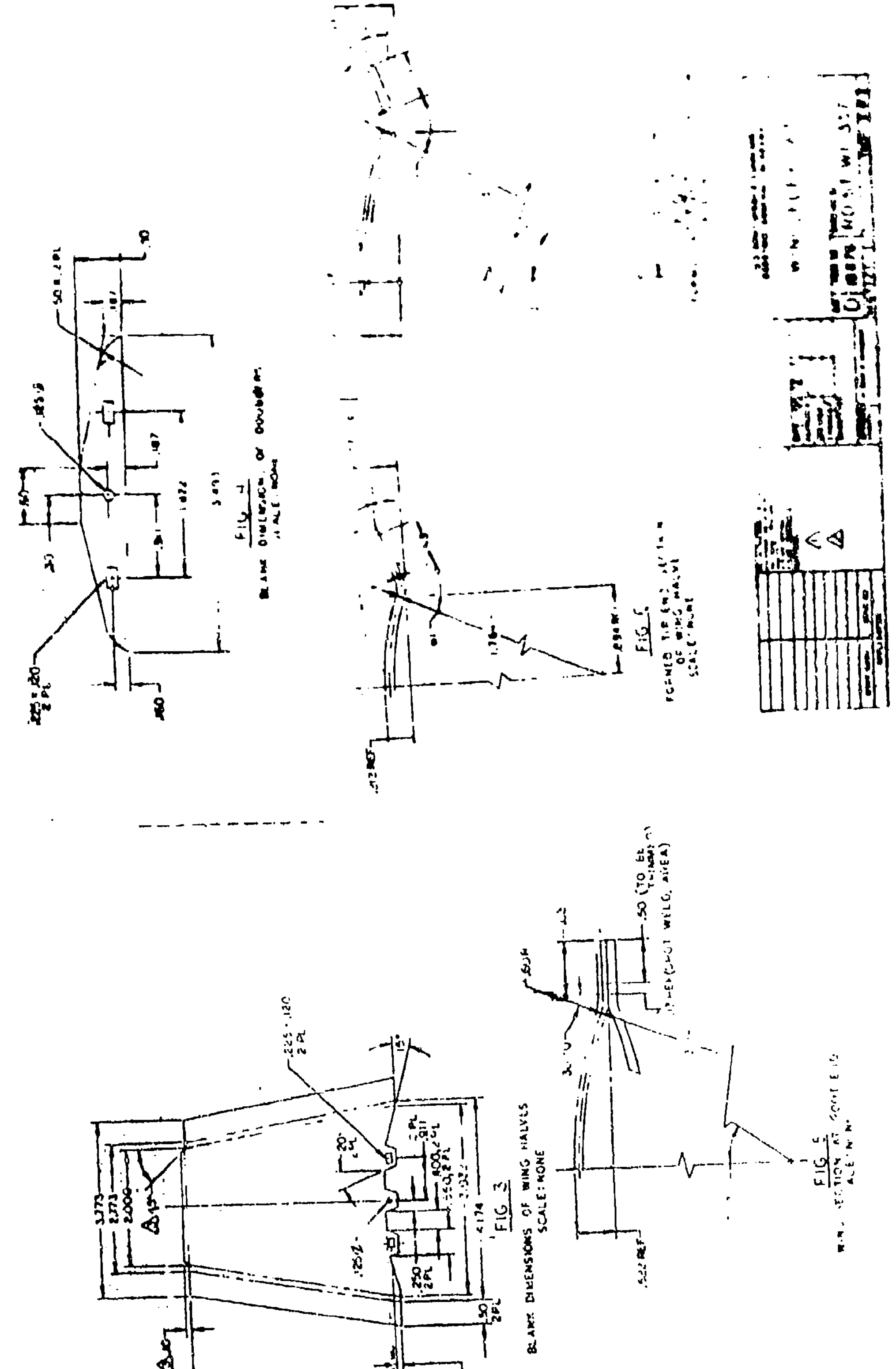


FIG 3
BLANK DIMENSIONS OF WING HALVES
SCALE: NONE
FIG 4
BLANK DIMENSIONS OF DOUBLER
SCALE: NONE
FIG 6
FORMED TIP END SECTION OF WING HALVES
SCALE: NONE
FIG 5
4.500
4.174
3.373
2.373
2.000

APPENDIX H

BLANKING PROCESS

Blanking Process

1. Practical tolerance for punching is ± 0.005 inches. If tolerance is below ± 0.003 inches on a blanked part, shaving is required to meet the tolerance. The conclusion from these rules is that the AATAC Flex-Wing, with a minimum tolerance of ± 0.005 inches, can be blanked with no finishing processes.

2. The width of any projection or slot should be at least 1.5 times the metal thickness, and never less than 0.094 inches.

$t = 0.016$ in.
$1.5 \times t = 0.024$ in.
0.024 in. > 0.094 in.
$\therefore$ 0.024 in. is the controlling dimension

slot width = 0.225 in.
0.225 in. > 0.024 in.

slot height = 0.120 in.
0.120 in. > 0.024 in.

tab width = 0.10 in.
0.10 in. > 0.024 in.

$\therefore$ slot and tab dimensions meet the above constraints

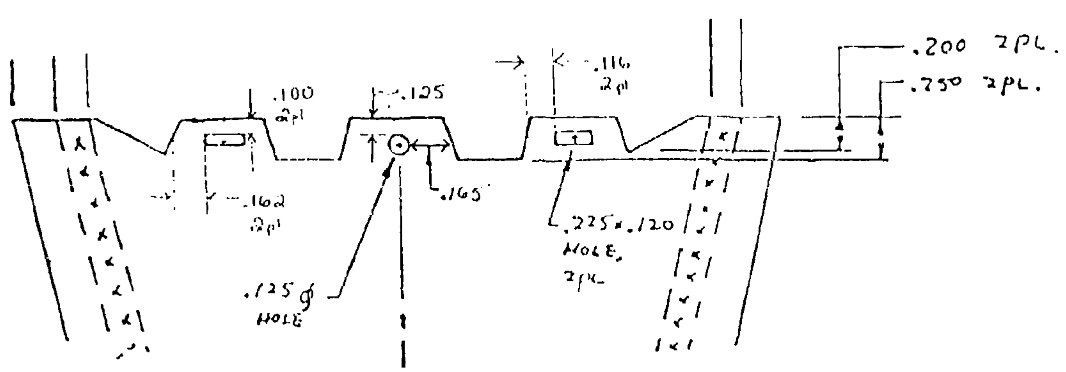
3. The diameter of pierced holes should not be less than the thickness of the metal or a minimum of 0.025 inches.

0.016 in. < 0.025 in.
$\therefore$ 0.025 inches is the controlling dimension

dia of hole = 0.125 in.
0.125 in. > 0.025 in.

$\therefore$ diameter of hole meets the above constraints

4. The minimum distance between holes or between holes and edge of stock should be at least equal to the metal thickness.



NOTE: All dimensions meet the above constraint.

FORMING

1. Hydroforming and the Guerin process are both drawing processes. A practical tolerance for drawing is $\pm$ 0.004 inches. Since this is a tighter tolerance than is necessary for the wing, there should be no problems meeting the tolerance requirements in the forming step.

2. A general tolerance review of the formed wing was performed. During this review, it was found that the radius and angle tolerances allowed an inner arc length tolerance of 0.03 inches at the root end, but the reference dimensions, hr and Wr, (Figure 3, Appendix A) controlled the arc length. These, and the other reference dimensions, on both the root and tip ends, are necessary to ensure the symmetry of the wing.

APPENDIX I

STRESS ANALYSIS

DISPOSITION FORM

For use of this form, see AR 340-15; the proponent agency is TAGO.

09 APR 1987

REFERENCE OR OFFICE SYMBOL	SUBJECT
AMSMI-RD-ST-SA	Stress Analysis for AATAC Flex Wing, Letter Report RD-ST-87-40

TO AMSMI-RD-ST-WF/Schexnayder FROM AMSMI-RD-ST-SA DATE 7 APR 1987 CMT 1
Mrs. Pirtle/dc/6-1712

1. The purpose of this task was to develop a finite element analysis model of the AATAC Flex Wing which can be used to evaluate the design.

2. The A1 and A3 flex wing basic models consisted of COSMIC NASTRAN CQUAD2 membrane and bending elements. The nodal geometry was prepared by graphically drawing the root and tip ends of the preformed wing half as accurately as equipment would allow. See Figures 1, 2, 3, and 4 for the geometries and the differences between the A1 and A3 flex wings*. Next, an equal number of nodal points was placed on the root and tip ends. The points were measured from the wing's centerline, with the origin located at the root end. These points were used to generate the remaining points from root to tip, thus defining the overall geometric nodal shape of the flex wing. The other half of the wing's nodal geometry was formed from symmetry. The elemental connections were made from root to tip, and from left to right. Figures 5 and 6 show the elements and nodes of the A1 and A3 flex wing models. Appendix A contains the basic A1 flexwing model in NASTRAN free-field form, and Appendix B contains the basic A3 flexwing model.

*NOTE: Figures 1, 3, and 4 were taken from the November 27, 1985 JPL Summary Report. See this report if further information on the geometry is desired.

3. To provide sufficient information for evaluation of the design, several computer runs were [illegible]de. The following is a list of the specific runs pertinent to the design bending load of [illegible]6.68 inch-pounds applied to the wing's root:

a. A1 flex wing with forming prestress.
A1 wind tunnel load case.
A1 buckling load.

b. A1 with no forming prestress.
A1 wind tunnel load case.
A1 buckling load.

c. Original model with modified doubler.
A1ID flex wing forming case.
A1 wind tunnel load case.
A1ID buckling load.

d. Modified doubler model with additional doubler outboard on wing/flex wing forming case.
A1 wind tunnel load case.
A1ID+D buckling load.

e. Case A with increased panel thickness from 0.012" to 0.014".

f. A3 flex wing forming case.
A3 wind tunnel load case.
A3 buckling load combination.

DA FORM AUG 80 2496 PREVIOUS EDITIONS WILL BE USED

g. Proposed A4 flex wing.
Case A with increased panel thickness from 0.012" to 0.016".

h. A3 flex wing forming case.
A3 wing collapsing load case.

i. A4 flex wing forming case.
A4 wing collapsing load case.

4. The following is a more detailed description of the cases listed above:

a. To form the desired shape and prestress in the wing, the seams on both sides of the wing are clamped and welded together. Then, the tip end is clamped together and a tab is bent to hold that shape. This process was simulated by using NASTRAN's enforced displacement capability, which yields the A1 flex wing in its finished condition. It should be noted that because of high forming stresses some plastic deformation often occurs in the real wing. Thus, an iteration process was performed to make the root chord thickness of the model represent the root chord thickness of the finished product. Also, it is important to notice the level of prestresses in some of the wing weld locations. Figure 7 shows the locations and values of the highest stresses that occur in the wing welds. They are not of concern considering the loads and material used. The wind tunnel load case as depicted in Figure 8 was simulated by applying a pressure field P to the wing surfaces using the equation: Cp * 2P * A = 246.68 in-lb, where Cp is the center of pressure and A is the total surface area. The wind tunnel load case as applied shows a crease on the Figure 9 plot in the area where buckling had occurred in the wind tunnel. To find out if this load did in fact cause buckling to occur, a buckling solution was run by combining the forming case and the wind tunnel case. The computer run indicates an Eigenvalue of .772 for the first mode of buckling in the direction of the load. This corresponds to a buckling load of 195 inch-lbs.

b. The A1 model was modified to remove the geometry that caused prestresses in forming. The run shows a buckling load of 147 in-lb. Thus, the prestresses contributed approximately 25% to the wing's load handling capability.

c. Figure 10 shows the location where additional elements were added to the A1 model in Case A to epresent the modified doubler. The effect of the modified doubler was insignificant. The buckling load increased 2.8%, and the center of buckling moved approximately 5% toward the tip of the doubler.

d. This case was done in the same manner as Case C. Refer to Figure 11 for the configuration of the additional doubler. The effect was much the same as the previous case, except that the center of buckling moved slightly toward the tip of the wing.

e. In this case, the only change in the A1 model was the panel thickness. The percent of design load increased from 77.2% to 90.9%, which is an overall increase of 13.7%.

f. Using a different geometry than the A1 flex wing, the forming process for the A3 was identical to the A1 flex wing (Case A). The highest stresses due to forming are 198,820 psi, and are located primarily in the wing's tip end welds. The wind tunnel load case on the A3 flex wing used the same procedure as did the A1 in Case A. To determine when buckling would actually occur, a buckling load case was applied to the A3 flex wing. The computer run shows an Eigenvalue of 1.75 which yields a buckling load of 432 in.lbs.

g. This case is the proposed A4 flexwing design. As in Case E, the only change in the model was the panel thickness from .012 inch to .016 inch. The A4 carried the wind tunnel load with a small margin of safety. However, the stress levels in the spot welds should be noted (see Case I, Table 1). The level of stress might lead to stress corrosion which might cause the wing to crack with age.

h. and i. Two runs were made on the A3 and A4 wings to predict the stress levels in the wings due to collapsing for storage. These also show stresses which might cause cracking due to stress corrosion. The highest stress indicated in Case H was 200,617 psi and the highest in Case I was 232,489 psi located at the tip spot welds.

5. Table 1 is a summary of the results of all the load cases.

6. CONCLUSIONS: From the Table 1 results, it can be seen that Cases F, G, and E give the highest buckling loads based on a 256.68 in-lb maximum bending load applied to the root of the wing.

7. MICOM - Providing Soldiers the Decisive Edge.

Delana A. Pirtle
DELANA A. PIRTLE
Struc Anal & Design Function
Structures Dir, RD&E Center

14 Encls
1. Table 1
2-12. Figs 1-11
13. Appendix A
14. Appendix B

CF:
AMSMI-RD-CS-T

CONCURRENCE:

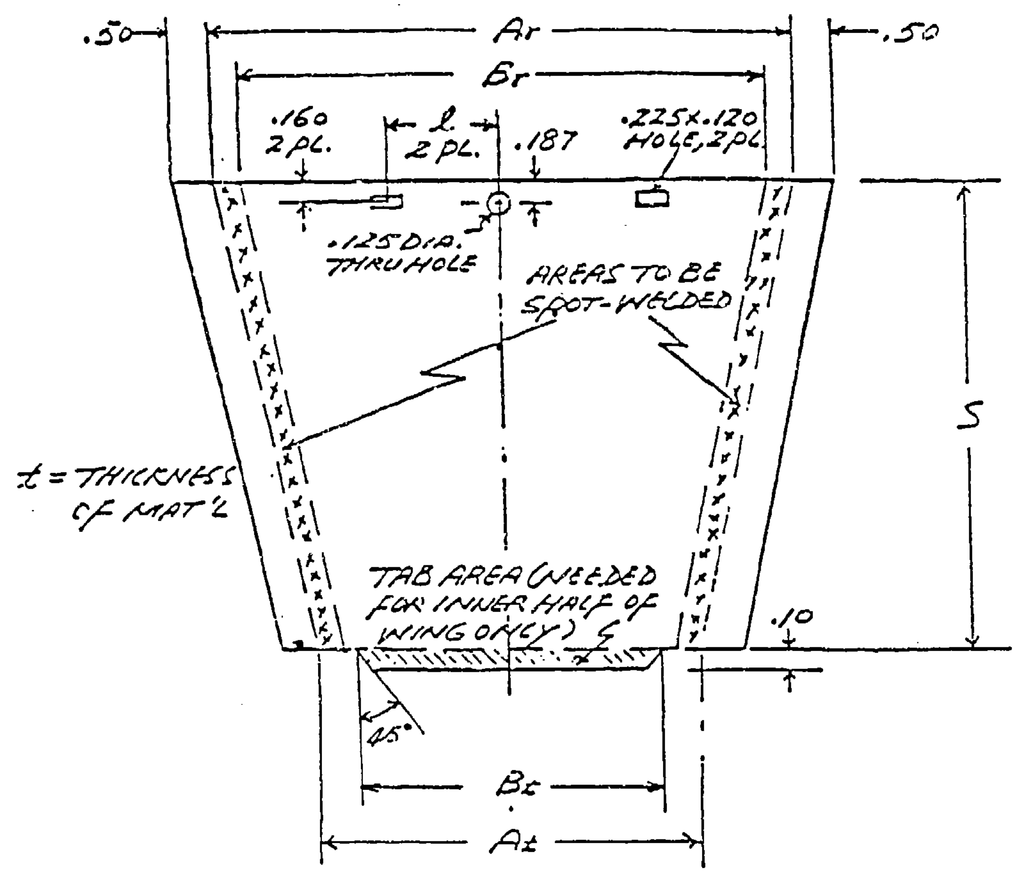
Larry C. Mixon
LARRY C. MIXON
Director, Structures Directorate
Research, Development, and
Engineering Center

3

TABLE I-1. Results of Load Cases.

CASE	RESULT
A	77.2% of design load caused buckling.
B	48.7% of design load caused buckling.
C	80.0% of design load caused buckling.
D	81.0% of design load caused buckling.
E	90.9% of design load caused buckling.
F	175.2% of design load caused buckling.
G	106.1% of design load caused buckling.
H	High stresses of 2.006E+05 PSI at tip spot welds.
I	High stresses of 2.3248E+05 PSI at tip spot welds.

NOTE: Cases H and I are listed to indicate concern about possible stress fatigue due to high storage stresses.



Design	t	s	Ar	Br	At	Bt	ℓ
A1	.012	4.60	4.139	3.879	2.773	2.00	.910
A3	.012	4.60	4.1/4	3.932	2.773	2.00	.911

Figure I-1. Blank dimensions of wing halves.

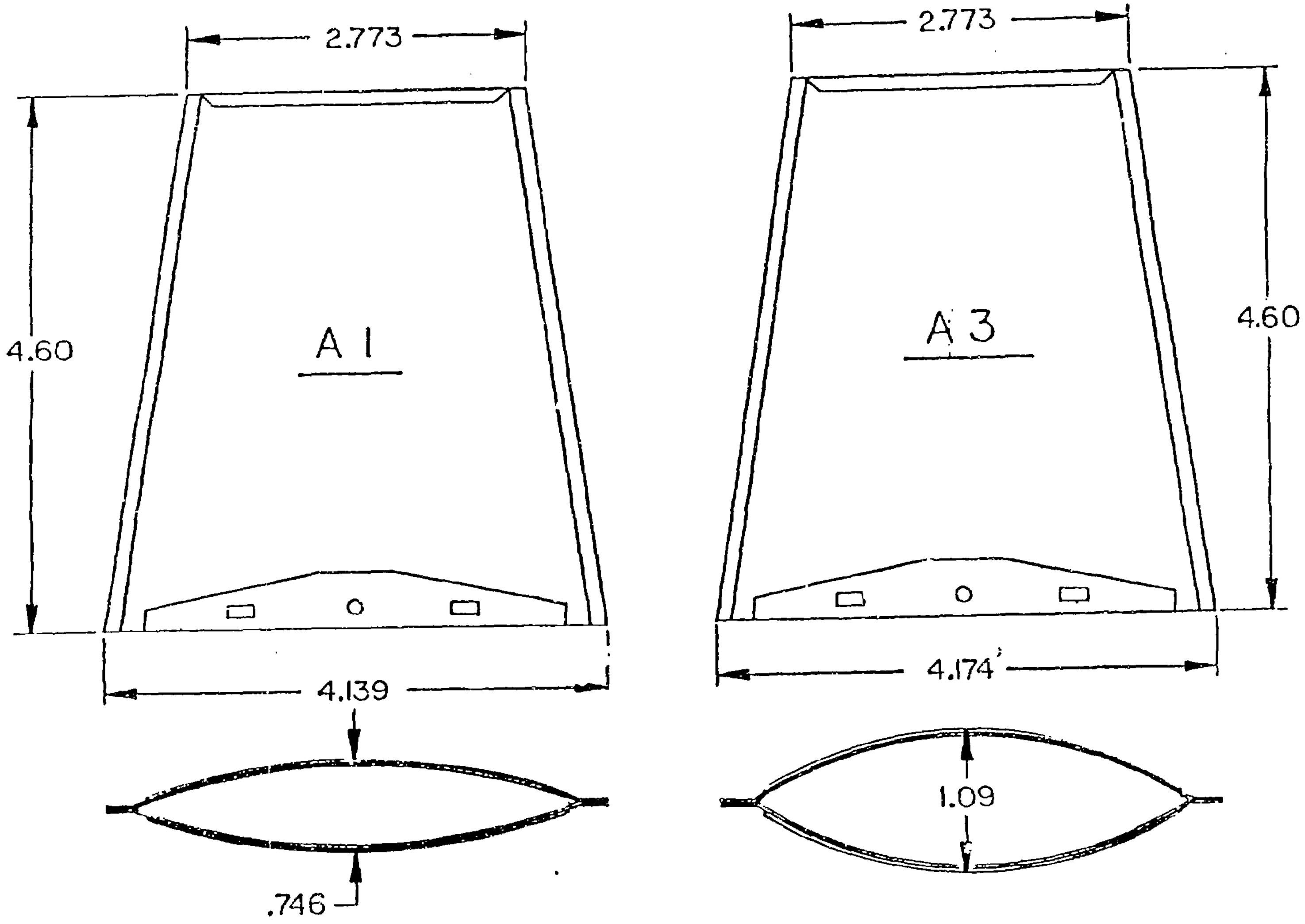
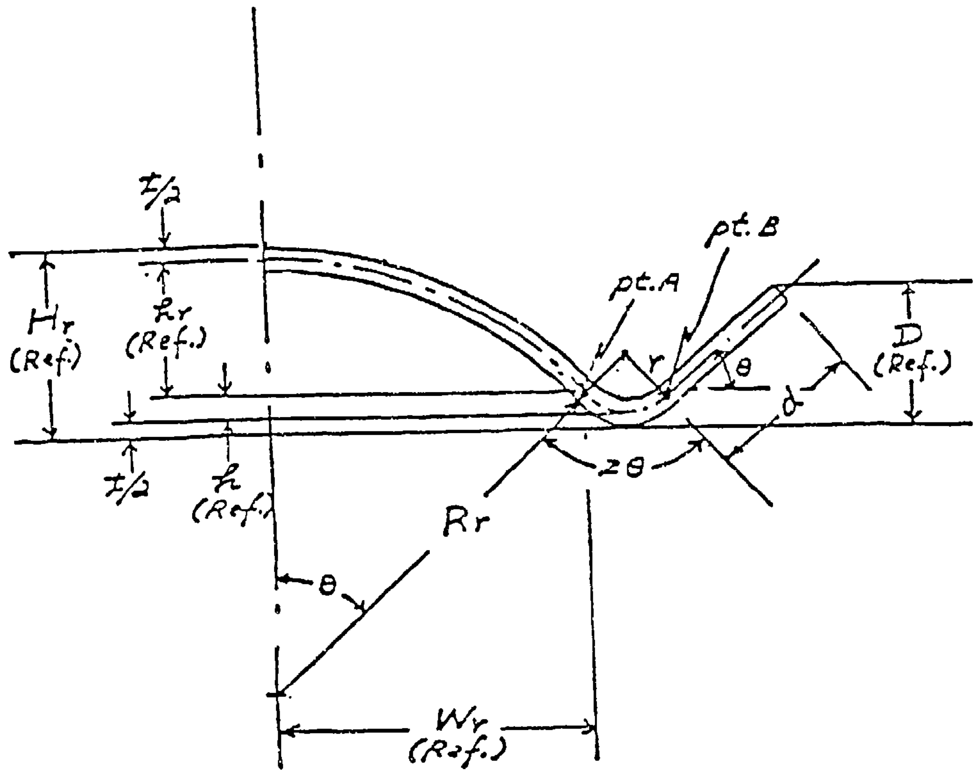
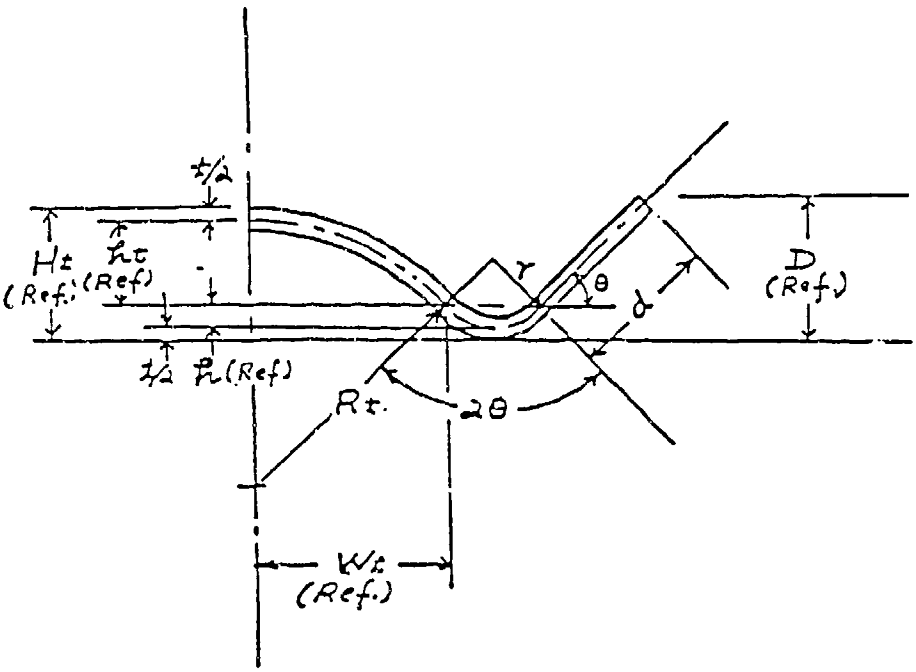


Figure I-2. A1 and A3 geometry differences.



Design	Rr	r	θ	t	d	D	hr	h	Hr	Wr
A1	4.929	.300	20.1°	.012	.63	.246	.300	.018	.330	1.694
A3	3.096	.300	30.5°	.012	.63	.371	.427	.041	.480	1.569

Figure I-3. Formed root-end section of wing halves.



Design	Rt	r	θ	t	d	D	ht	h	Ht	Wt
A1	2.980	.30	20.1°	.012	.63	.246	.182	.018	.212	1.024
A3	1.764	.30	30.5°	.012	.63	.371	.240	.041	.293	.894

Figure I-4. Formed tip-end section of wing halves.

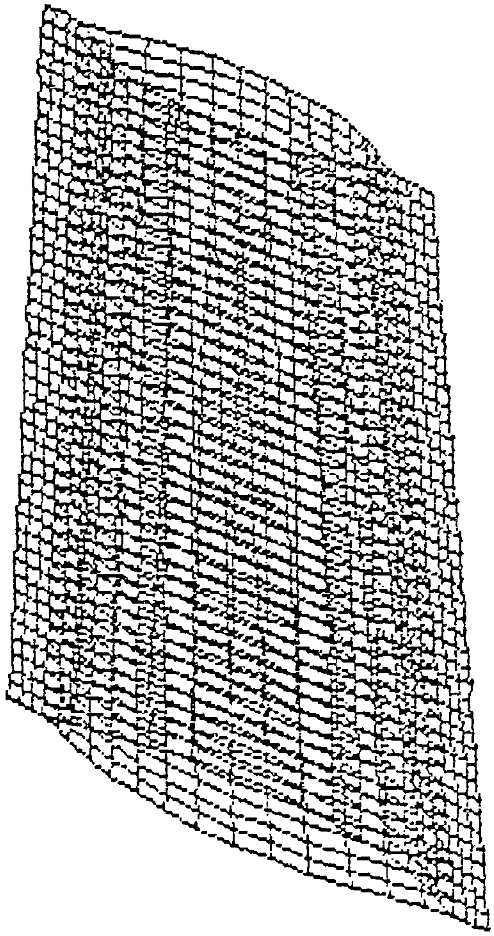


Figure I-5. Al flex-wing forming case.

2/20/87

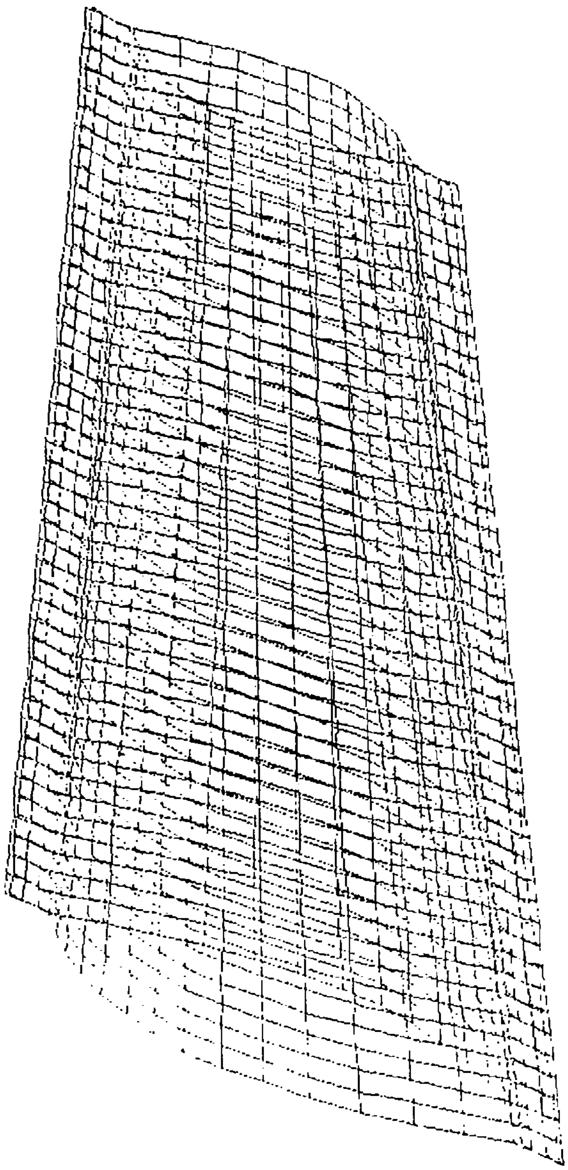


Figure I-6. A3 wing forming case.

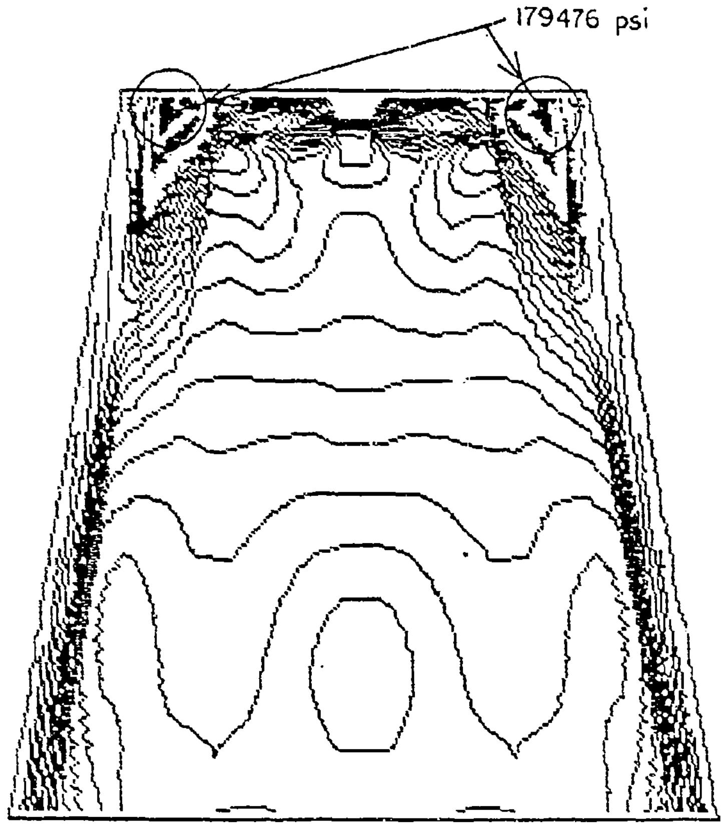


Figure I-7. Prestresses in wing welds.

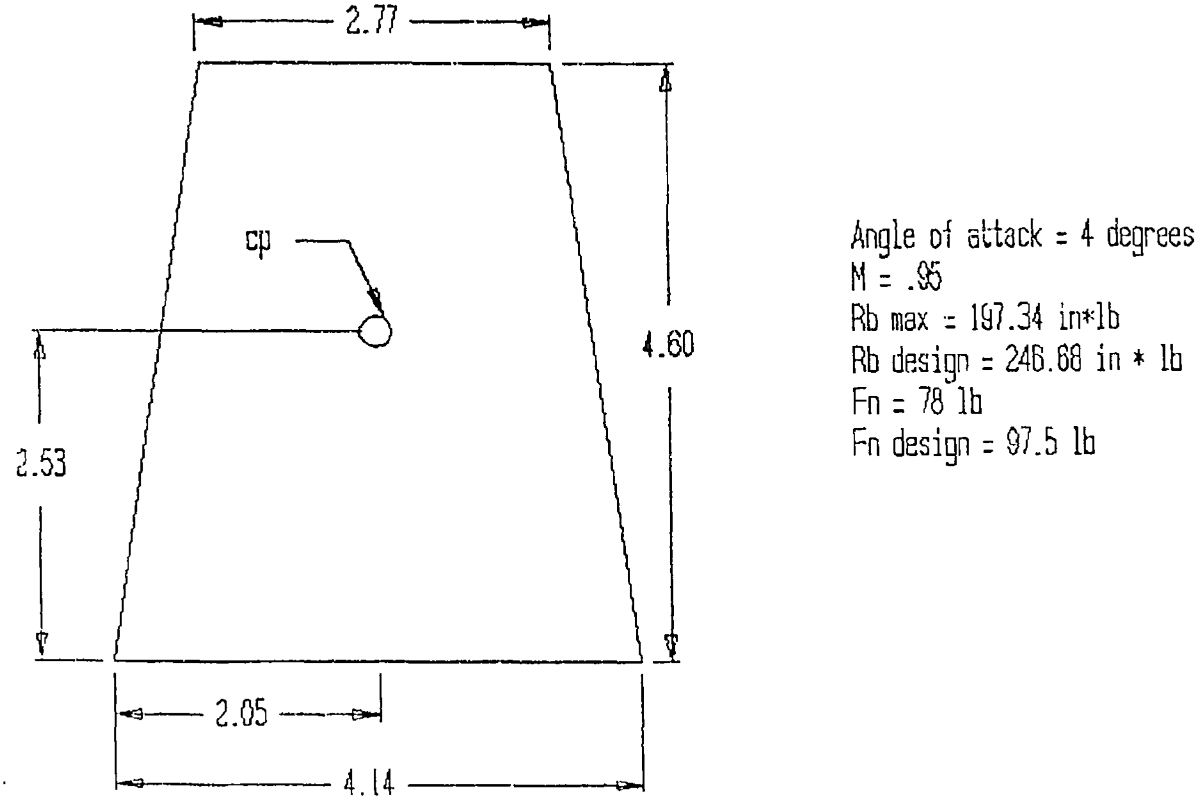


Figure I-8. Wind tunnel load case.

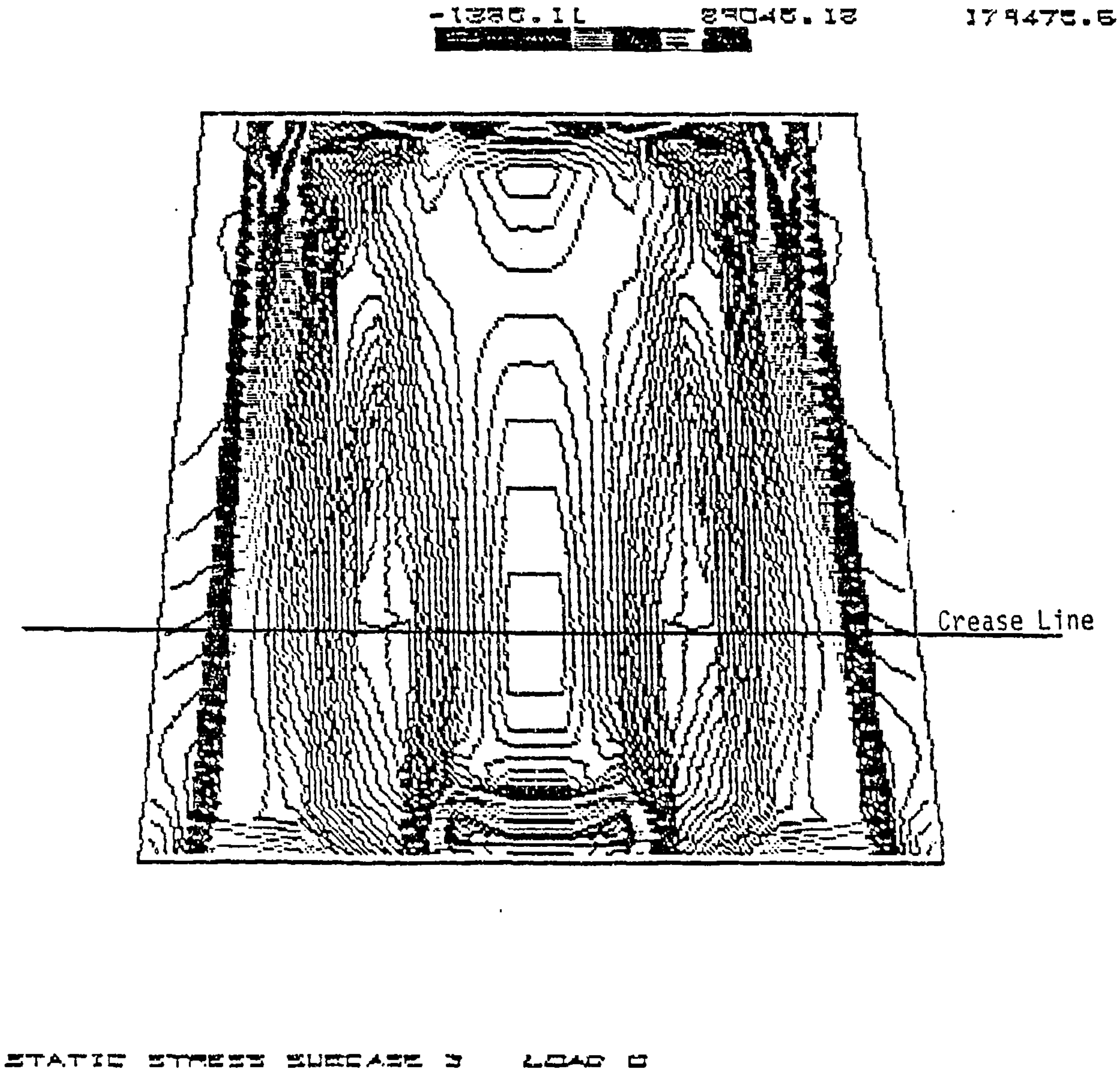


Figure I-9. Al flex-wing wind tunnel load case.

DISTRIBUTION

	Copies
IIT Research Institute ATTN: GACIAC 10 W. 35th Street Chicago, IL 60616	1
U.S. Army Materiel Systems Analysis Activity ATTN: AMXSY-MP Aberdeen Proving Ground, MD 21005	1
AMSMI-RD, Dr. McCorkle	1
Dr. Rhoades	1
AMSMI-RD-ST, Dr. Mixon	1
AMSMI-RD-ST-WF, Mr. Lovelace	5
Mr. Cornelius	5
AMSMI-RD-SE, Dr. Daniel	1
Mr. Williams	1
AMSMI-RD-SE-PE, Dr. Donnelly	1
Mr. Hodges	1
Mr. Beason	1
Mr. Amos	5
Ms. Robertson	1
Mr. Brewer	1
Mr. Wood	5
Ms. Bowles	1
Cape Lab (Mr. Wood)	1
AMSMI-RD-CS-R	5
AMSMI-RD-CS-T	1
AMSMI-GC-IP, Mr. Fred Bush	1

DEPARTMENT of DEFENSE

Directorate for Freedom of Information and
Security Review, Room 2C757
1155 Defense Pentagon
Washington, DC 20301-1155

Facsimile Transmittal

30 November 2001

To: Mr. Larry Downing

Organization: DTIC
Office Phone:
FAX Number: (703) 767-9244

From: Sharon Reinke, Navy Division, DFOISR/WHS/DOD

Phone: (703) 697-2716
FAX: (703) 693-7341

Total Pages Transmitted (including cover sheet): 04

Comments: I am forwarding the FOIA request DTIC received, the DTIC forwarding letter, and a list of documents. The documents in the attached list have been released to a FOIA requester [under our case number 01-F-2458] and are, therefore, cleared for public release. If you have questions, give me a call.

AMERICAN LAWYER MEDIA
105 MADISON AVENUE, NEW YORK, NY 10016
212-779-9200

01-F-2458

April 11, 2001

Defense Technical Information Center
Attn: Kelly Akers, FOIA Manager
8725 John J. Kingman Road Suite 0944
Fort Belvoir, VA 22060-6218

FOIA REQUEST

Dear Ms. Akers:

American Lawyer Media respectfully requests, under the Freedom of Information Act, a copy of each of the following records:

AD B253477, XV-8A Flexible Wing Aerial Utility Vehicle, by H. Kredit, January 1964, 144 pages

AD B252433, Pilot's Handbook for the Flexible Wing Aerial Utility Vehicle XV-8A, March 1964, 52 pp

AD B200629, Flex Wing Fabrication and Static Pressure Testing, by Larry D. Lucas. June 1995, 80 pages

AD B198352. Materials Analysis of Foreign Produced Flex Wings. by Albert Ingram, march 1995, 16 pp.

AD B131204, Active Flexible Wing Technology, by Gerald D. Miller, Feb. 1988, 256 pages

AD B130217, Producibility Analysis of the Alternative Antitank Airframe Configuration Flex Wing. June 1988, 112 pages

AD B126450, From Delta Glider to Airplane. June 1988, 5 pages

—AD ~~B~~803668, Sailwing Wind Tunnel Test Porgram, September 1966, 125 pages

AD 477 482, An Evaluation of Flex-Wing Aircraft in Support of Indigenous Forces Involved in Counterinsurgency Operations by R.A. Wise, Feb 1965, 74 pages

—AD 461202, XV-8A Flexible Wing Aerial Utility Vehicle, H. Kredit, Feb. 1965, 100 pages

—AD 460405, XV-8A Flexible Wing Aerial Utility Vehicle, Final Report. Feb. 1965, 113 pages

—AD 431128, Operational Demonstration and Evaluation of the Flexible Wing Precision Drop Glider in Thailand, by William R. Quinn, November 1963, 22 pages.

AD 430150, Comparative Evaluation of Republic Bikini Drone System, Final Report, 1943?

We agree to pay up to $200 for costs associated with this request. We are grateful for your kind assistance in this matter. Please contact me at 212-313-9067 if you have any questions relating to our request.

Sincerely,

Michael Ravnitzky
Editor

Encl 1